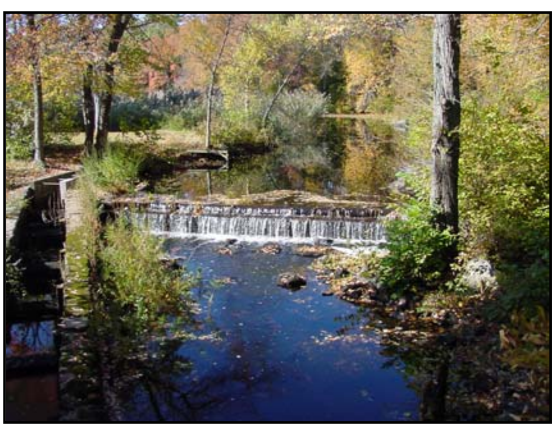
Executive Office of Environmental Affairs
Massachusetts Watershed Initiative

Parker River Low Flow Study



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Executive Summary

Introduction

The Parker River watershed, with a drainage area of 82 square miles, is a coastal river system located in the northeast corner of Massachusetts. The watershed is situated between the Merrimack River watershed to the north and the Ipswich River watershed to the south. The Parker River originates in the Town of Boxford and flows easterly for approximately 21 miles before emptying into Plum Island Sound, near the City of Newburyport. The mainstem Parker River has a drainage area of 32.6 square miles; 25 square miles comprise the freshwater portion, while the remainder is tidally influenced. Major tributaries to the tidal portion of the Parker River include the Mill River (drainage area of 18 square miles) and Little River (drainage area of 10.7 square miles). The Egypt and Rowley Rivers (total drainage area of 9.6 square miles), as well as the Plum Island and Eagle Hill Rivers (total drainage area of 12.0 square miles) empty into Plum Island Sound.

A previous statistical analysis, completed by the Massachusetts Department of Environmental Management (MDEM), of United States Geological Survey (USGS) streamflow data indicated that recent low flow conditions in the Parker River above the Byfield gaging station (in operation since October 1945) were lower than historic averages. In addition, during portions of August and September of 1997 approximately 0.5 miles of the Parker River became desiccated in the area above Bailey Lane in the Town of Georgetown (PRCWA 2001). The desiccated reaches were located downstream of several municipal water supply wells operated by Georgetown.

Maintaining appropriate flows in river systems is important to sustain aquatic biota (i.e., fish, amphibians, macroinvertebrates and plants) and the entire river ecosystem as a whole. Over time, the aquatic biota within the Parker River have adapted to the natural flow regime. In particular, aquatic biota have adapted to tolerate the critical summer low flow period, which typically occurs during the July-September timeframe. With increasing pressures from human development, the magnitude of these summer low flows can diminish and persist for much longer periods than would otherwise occur naturally. As a result, habitat for aquatic biota can diminish severally, which can lead to mortality. In addition, unnatural low flow conditions can result in water quality degradation (higher temperatures, lower dissolved oxygen levels, water odor).

This study was commissioned by the Executive Office of Environmental Affairs (EOEA) Watershed Initiative and the Parker River Watershed Team. The principal study area was focused on the watershed above the Byfield USGS streamflow gage, which has a drainage area of 21.3 square miles. The study determined the timing and magnitude of low flow reduction in the Parker River. Additionally, the following potential causes of the reduced low flows were investigated.

- Natural variations in the hydrologic cycle (i.e., reduced and/or changes in the timing precipitation);
- Increasing water withdrawals for public water supply and industrial uses;
- Increased urban development/growth within the study area; and
- Increased beaver activity within the study area.

Summary of Key Study Findings and Results

<u>Occurrence of Low Flow Events</u>

The study used several statistical methods to analyze streamflow data from the Byfield USGS gage, and confirmed that the occurrence of unusually low flow events in the Parker River has increased in recent times. In particular, flows during the months of June, July, August and September were significantly lower during the Water Year[1] (WY) 1990-2002 period, when compared to WY 1946-1989.

The USGS Streamstats program was used to estimate a completely unregulated/natural flow regime to assess the degree of impact that human and other activities may have on streamflow. For several low flow statistics, the program predicted higher flow values, compared to the same low flow statistics computed from actual flows measured at the Byfield USGS gage for the 1990-2002 period. The flow values measured during the historic period (WY 1946-89) were generally within the range predicted by the Streamstats program.

Water Withdrawals

The study found that increases in annual and seasonal (summer peak period) water withdrawals for public water supply and industrial uses are the most significant factor affecting the occurrence of low flow events in the Parker River. Although the entire study area returns wastewater to the watershed via septic systems, increased summer water use and evaporative losses from irrigation and plant transpiration effectively remove water from the local hydrologic system and it is not returned to the river.

Based on the overall magnitude of its withdrawals relative to other users, and the significant rate of increase in its withdrawals over time, Georgetown Water Department (GWD) appears to have the greatest impact on Parker River streamflows. GWD's annual withdrawal volume has risen consistently between 1990 and 2001. Daily water use in Georgetown increased steadily from 0.49 MGD in 1990 to 0.72 MGD in 2001, an increase of 48%. During this same period, the population of Georgetown grew by 16%.

Georgetown Sand and Gravel (GSG's) total annual withdrawals have reportedly decreased in recent years, and therefore appear to have less impact on streamflows, relative to GWD. However, GSG does withdraw water directly from the Parker River, which results in more direct adverse impacts on streamflow, relative to pumping from a well. GSG's withdrawal volume has ranged from 0.52 MGD in 1997 to 0.18 MGD in 2001. GSG is reportedly discontinuing their operation in the near future.

Relative to GWD and GSG, water withdrawals by Byfield Water District (BWD) likely impact streamflow the least. The overall magnitude of water withdrawals made by BWD is less than the other two water users. BWD recently (1998) installed a deep bedrock well near Forest Street to serve as its primary water source. This well has a lesser degree of hydraulic connectivity to the river compared to GWD's shallow gravel wells, and certainly less of a direct impact compared to GSG's surface water withdrawal. In recent years, BWD occasionally made secondary water withdrawals from its Larkin Road well, which was previously discovered to have a high degree of hydraulic connectivity to the Parker River. BWD's withdrawal volume has ranged from 0.16 MGD in 1994 to 0.22 MGD in 1999. Daily water use increased from 0.17 MGD in 1990 to 0.20 MGD in 2001, an increase of 14%. The service population of Byfield grew 12% from 1990 to 2000.

Water demand in the study area continues to increase from new users as well. Relative to the public and industrial water users, Georgetown Country Club's (GCC's), which began operation in 1997, water use is relatively low compared to the other three major users; however, most of this water is used for irrigation

[1] The USGS typically reports surface water data in terms of a water year, which is the 12-month period of October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year beginning October 1, 1945 and ending September 30, 1946, is called the "1946 water year". For purposes of comparison, precipitation data was also analyzed by water year as well.

during the summer season, which likely results in high evapotranspiration rates and very little of the withdrawn water being returned to the watershed. GCC's annual withdrawal volume has reportedly ranged from approximately 0.06 MGD for the 1997-1999 period to 0.05 MGD in 2002.

Further exacerbating the problem of increasing annual water withdrawals in the study area is the seasonal (summer period) increase in water demand as well. It is suspected that outdoor water use (in the case of the public water suppliers and the golf course) is primarily responsible for the increased summer water demand. The peak day to average daily withdrawal ratio for GWD and BWD is 2.36 and 2.28, respectively. Generally, ratios above 1.5 are considered excessive, and an indication that the water demand is in need of more effective management.

The increase in summer water demand typically occurs when streamflows are already at their lowest levels for a given year. For the period 1990-2001, during the months of July, August, and September, total water withdrawals in the study area are 31%, 40%, and 25%, respectively, of the average monthly flow measured at the Byfield USGS gage. During dry summers such as 1997, GWD's and GSG's water withdrawals for the months of July, August, and September were 309%, 1,526%, and 1,641% greater, respectively, than the average monthly flow measured at the Byfield USGS gage. In the dry summer of 2001, this situation even carried over into the months of October and November when total water withdrawals from all three major users exceeded average monthly streamflow by 911% and 193%, respectively. The water withdrawals are effectively taken from the river or intercepted before the water would have recharged the river.

Urban Development/Growth

Urban development/growth within the study area has moderately impacted Parker River streamflows. Increases in the amount of impervious surfaces such as roofs, roads, sidewalks, and parking lots have resulted in changes to streamflow dynamics in the study area. Since precipitation cannot infiltrate these surfaces, it runs off, reaching nearby streams faster compared to natural conditions; thus, increasing flood peaks and decreasing groundwater recharge and in turn base flow[2].

A land use trend analysis completed for the study area revealed a 10.1% increase in residential land use since 1971. This increases impervious surfaces, reduces infiltration and increases water demand (lawn irrigation). In a coincident timeframe, forest and agricultural land decreased 8.1% and 2.4%, respectively. The resulting increases in impervious area from residential development increased flood peaks in the watershed over time, as well as contributed to decreases in base flow. Peak flood flows for the WY 1946-2002 period increased significantly over time. The streamflow rise and fall rates, which are indicators of how quickly runoff reaches nearby streams, increased over time. Low flow statistics for the WY 1946-2002 period indicated that low flows moderately decreased over time, meaning that base flows have been reduced.

Precipitation Patterns

Natural variations in the hydrologic cycle (i.e., precipitation patterns) have had a marginal impact on the occurrence of unusual low flow conditions in the Parker River. Comparisons of annual average precipitation for the periods WY 1946-89 and WY 1990-2002, revealed that the WY 1990-2002 period received on average approximately 2 more inches (4.3% higher) of precipitation per year. It would be expected that streamflow would be higher for the recent period; however, the average annual streamflow (runoff) for both periods is essentially the same-indicating that Parker River flows have been depleted during the recent period.

[2] Base flow is the sustained low flow in a stream; groundwater discharge is the source of base flow in most places.

A comparison of historic dry periods (WY's 1957, 1965, and 1966) with recent dry periods (WY's 1995, 1997, and 2002) showed that even though the historic dry years had lower precipitation levels relative to the dry years in the recent period, key low flow statistics were higher during the historic years. Thus, our recent droughts have been less severe, yet the river is being more severely depleted.

Beaver Activity

Beaver dam impoundments have both beneficial and detrimental effects on stream hydrology. The water surface area created by an impoundment can result in increased evaporation rates, particularly during the summer. The impoundment can be beneficial to water supply, by acting to recharge groundwater levels in adjoining aquifers, by slowing the flow rate and allowing increased infiltration to depleted aquifers.

Beaver activity along the mainstem of the Parker River has a relatively minor impact on streamflow conditions. Most of the beaver impoundments along the Parker River are not large enough to significantly decrease streamflow via evaporative processes. The impoundment located within the GWD well complex is quite large in size; however, topographic maps suggest this impoundment was in place prior to the WY 1990-2002 period of decreased streamflows. It is also likely that this impoundment serves a beneficial purpose to water supply by enhancing recharge into the aquifer that serves the well complex.

Study Recommendations

Based on the study conclusions, several recommendations are proposed to better manage the water resources of the Parker River watershed, as well as address key impacts identified by the various analyses. The recommendations are divided into three categories; general, short-term, and long-term.

General Recommendations

General recommendations were developed to address issues that were encountered during the study process. In some cases, these issues hampered the analyses conducted within the study. These recommendations are made in an effort to avoid similar issues during future studies of this kind.

- It is recommended that the Massachusetts Department of Environmental Protection (MDEP) improve efforts to verify the accuracy of all future data reported on Water Supply Annual Statistical and Registered & Permitted Withdrawals Annual Reports as part of the Water Management Act. Beyond reporting accuracy issues, MDEP should consider effects of streamflow depletion being caused by the water withdrawals in its review and renewal of WMA permits.

Short Term Recommendations

Short term recommendations were developed to address the impacts identified within this study. These recommendations are relatively modest and could be implemented within one year or sooner of the study publication date. Also, these recommendations are considered to be relatively inexpensive to implement, but could potentially have far-reaching benefits in alleviating the low flow conditions experienced in the Parker River.

The results of this study indicated that increased water withdrawals, particularly by GWD, for public water supply and industrial uses were the most significant factor affecting the occurrence of low flow events in the Parker River. Of particular concern was the problem of the seasonal increase in water demand that typically occurs during the summer period. Evidence shows that outdoor water use is primarily responsible for the increased summer water demand. It is recommended that the initial steps to mitigate the low flow problem in the Parker River focus on decreasing peak summer water demand, so that existing water supplies are sufficient to serve needs, while reducing environmental impacts to water resources. The short term recommendations fall into two subcategories; immediate measures to better manage water use and demand during particularly sensitive periods, and approaches to gain more data to better quantify the cause of the problem.

- Both GWD and BWD have mandated outdoor watering restrictions in recent years during dry periods. It is recommended that GWD and BWD take additional measures to enforce compliance with the existing restrictions, as well as increase public outreach to educate end-users of the need for water conservation during these critical periods. If there is a high rate of compliance, then more stringent water restrictions are warranted during dry periods to decrease water demand. For example, the odd-even watering restrictions that are currently implemented may have little impact if automated sprinkler systems are operating at every opportunity. Allowing outdoor water use only one or two days a week and/or during limited hours may be much more effective. In some areas of the country, water users are asked to follow an every-third-day (at most) watering schedule for lawns, and water only between 8 p.m. and 8 a.m. to reduce water lost to evaporation. BWD's peak day to average daily withdrawal ratio dropped noticeably in 2000 (1.55) and 2001 (1.88). It is possible that more effective water conservations measures are responsible for this decline.

- Both GWD and BWD have peak day to average daily withdrawal ratios exceeding 2.0 for the period 1990-2001, which is considered excessive. Through aggressive water conservation measures and public outreach, GWD and BWD should limit this ratio to 1.5, as well as cap gallons per capita day use to 65. In addition, both GWD and BWD should take measures to limit unaccounted for water to 10% or less if possible. The water conservation measures should be aggressive in nature, as a substantial drop in water use will be necessary to achieve these limits. MDEP should incorporate these new, more stringent, limits into the next 5-year water withdrawal permit for each water supplier.

- BWD historically used the Larkin Road well to supplement their Forest Street well withdrawals during peak periods. The Larkin Road well was previously discovered to have a high degree of hydraulic connectivity to the Parker River. BWD should evaluate this management practice to ensure it is the most effective method of providing water. It may be beneficial to increase the pumping rate at the Forest Street well, which presumably has a lesser degree of hydraulic connectivity to the river, rather than rely on Larkin Road well to meet peak demand.

- The fact that GSG withdraws water directly from the Parker River, as opposed to pumping from a well, likely has a more direct adverse impact on streamflow. If GSG continues their operation, it is recommended that they investigate the possibility of establishing an on-site water source, such as a well, to replace the surface water withdrawal, which would have less direct impacts on streamflow.

- GCC began withdrawing water for irrigation purposes in 1997. Based on the research conducted during this study, it does not appear that GCC has been required to report their water use. The need for GCC to obtain a permit and report their withdrawals under the provisions of the WMA should be evaluated by MDEP. According to GCC, approximately 37 acres of the golf course facilities are irrigated. The MDEP Golf Course Water Use Policy presumes that courses irrigating 35 acres or more categorically exceed the WMA permit threshold of 9 MG during the peak 3 month irrigation period. Management practices to reduce the amount of acreage irrigated should be evaluated and implemented, as the majority of water typically used for irrigation is lost via evapotranspiration processes.

- Development, resulting in changes to land use, within the study area was found to have moderately impacted Parker River streamflows. Zoning changes or bylaw creation to assist communities in reducing future water use is imperative. It is recommended that local planning boards carefully scrutinize new applications for large-scale development (i.e., large subdivisions, golf courses, etc.). Planning Boards may wish to consider implementing a water bank or otherwise mandate mitigation measures to off-set the impacts of future developments to assure these do not place further demands on the water systems and exacerbate low-flow conditions on the Parker River. Other techniques for reducing environmental impacts of development are to prevent removal of topsoil from sites, limit the area disturbed on building sites, limit the area of lawn that is allowed on lots, and promotion of alternative lawn and landscape designs. These steps reduce the amount of water used in landscape establishment and maintenance. Some towns are also considering a ban on automated sprinkler systems or mandating water sensors that prevent the sprinkler system from activating when it is raining. Studies show that homes with automatic sprinklers use up to 30% more outside water than homes with manual systems. Also, installation of drip irrigation systems for non-turf areas can increase water use efficiency up to 75%.

- Rivers either gain water from inflow of groundwater (gaining stream) or lose water by outflow to groundwater (losing stream). Many rivers do both, gaining in some reaches and losing in other reaches. The flow directions (gaining or losing) between groundwater and surface water can change seasonally as groundwater levels change in response to the streamflow and precipitation levels, as well as groundwater pumping rates. It is likely that the reach encompassing the GWD well field has a high degree of hydraulic connectivity to the river and is both a gaining and losing stream under various hydrologic conditions. It is recommended that two gages be installed at the endpoints of this reach to continuously monitor streamflow levels. Additionally, groundwater levels in the reach should be monitored, either by the existing wells or by newly installed monitoring wells. These data, in conjunction with precipitation information, would be useful to help understand the timing and magnitude of the gaining/losing stream dynamic. It would also be useful to document if the water table is being gradually lowered at the river as a result of increasing groundwater withdrawals. This understanding could be used to better manage (limit) pumping rates during critical periods based on streamflow and groundwater conditions.

- It is recommended that the public water suppliers develop drought management plans, which incorporate current aspects of their water conservation strategy as well as the recommendations described above. The primary objective of a plan would be to assist communities in managing water used for lawn and landscape maintenance during dry periods or water shortages. The plans should consist of a series of “drought indicators” such as precipitation, groundwater, and/or streamflow levels that can be used to assess the severity of a dry period. In response to a particular drought severity level, appropriate water use restrictions should be developed. Water restrictions should be enforceable restrictions that are implemented through the municipality’s water use restriction by-law or by the regulations of a water district. The by-law should provide for a graduated system of increasingly stringent restrictions, culminating in a ban on outdoor water use, so that a water supplier can implement an appropriate response based on the severity of dry conditions or water supply problems. Communities that have insufficient water supplies may implement parts of their plan during non-drought years to help reduce peak demands that threaten the water supply system or the environment.

<u>Long Term Recommendations</u>

Several long term recommendations were also developed to address the impacts identified within this study. These recommendations are broader and more aggressive in scope, and would require more time and funding resources than the short term recommendations. The long term recommendations fall into two subcategories, measures for further study of the issue and approaches to more efficiently manage the water supply system.

- It is recommended that a safe yield analysis, relative to groundwater supply withdrawals, be conducted within the study area, as well as the remainder of the Parker River watershed. Safe-yield is the total quantity of groundwater that can be artificially withdrawn from an aquifer for water supply; and which naturally discharges to a stream without exceeding the aquifer recharge value for the area of consideration. Identifying and maintaining safe yield withdrawals will prevent long term and short term aquifer depletion, and in turn prevent streamflow capture (i.e., excessive loss of streamflow from groundwater pumping). An additional component of the safe-yield analysis should include an instream flow study, which will assist in determining appropriate minimum streamflow levels necessary to sustain aquatic habitat in various sections of the river.

- This study was focused on the watershed area upstream of the Byfield USGS gage. The main relevance of selecting the Byfield USGS gage as the downstream limit of the study area was that the data generated from it helped to identify the occurrence of the unusual low flow conditions. There are several other significant streams located within the watershed that could be similarly impacted by water withdrawals. These include the remaining freshwater portion of the Parker River, the Mill River, and the Egypt River. These streams are not equipped with flow monitoring devices, so there is no way to confirm and quantify the magnitude of the suspected problem. It is recommended that flow monitoring be instituted on these streams. Additionally, if streamflow depletion is identified, then studies should be completed to identify the causes and offer remedies to the problem.

- The results of this study indicated that increased water withdrawals for public water supply and industrial uses were the most significant factor affecting low flow conditions in the Parker River. Of particular concern was the problem of the seasonal increase in water demand that typically occurs during the summer period. Neither GWD, BWD, nor GSG have significant water storage capabilities that could be utilized during the peak demand periods to curb water withdrawals during periods of low flow. It is recommended that water storage options on a micro and macro scale be investigated. On a macro scale, water storage reservoirs would ideally limit the need to increase summer withdrawals and thus lessen the impact on streamflow. Creation of new reservoirs would allow storage of excess spring runoff, and allow for augmentation of summer demand by drafting water from storage. Previous studies (Metcalf and Eddy 1973) have identified potential sites for surface water reservoirs. The pros and cons of developing these water storage reservoirs would also have to be carefully evaluated in terms of regulatory hurdles, permitting process, hydrologic evaluations, environmental impact analysis, economics, and the political landscape. On a slightly smaller scale, both GWD and BWD have water storage tanks; however, their capacity is only sufficient to supply water for a short period of time. Both water suppliers, as well as, GSG should explore options to develop more substantive storage of this type. On a micro scale, developing small storage tanks for subdivisions to provide non-potable, outdoor water supply to offset summer demands should be investigated. Residential homeowners should be encouraged to utilize cisterns and rain barrels to collect and store rainwater for outdoor use. (1,000 square feet of roof can collect 420 gallons of water from 1 inch of rain. The water collected in a cistern, can be siphoned off to water gardens or wash cars).

- It is recommended that GWD, GSG, and BWD investigate the possibility of importing water to the study area for use during critical periods. Imported water would reduce the reliance on water withdrawals from/near the Parker River. The Ipswich River watershed has experienced problems with excessive water use, and would not be a candidate for providing water. However, other neighboring watersheds with storage capacity could be possibilities to provide supplemental water during critical periods. Any plan to import water would need to be consistent with the Massachusetts Interbasin Transfer Act, which has jurisdiction over transferring water outside of town and watershed boundaries via water supply and wastewater disposal.

- It is recommended that GWD, GSG, and BWD, as well as other major water users in the entire Parker River watershed develop a long-term regional public water supply plan to meet current and projected water needs (as opposed to demands). The water supply plan should incorporate facets of the previous recommendations (i.e., water conservation measures, safe yield analysis, potential for water storage). Additionally, the findings of this study indicated that the Parker River suffers somewhat from the uncoordinated management of several relatively small water users/providers. The water resources of the Parker River watershed may benefit from more consolidated management of this resource. A regional water authority or board comprised of representatives from all water users/providers in the watershed should be formed, with the mandate of implementing the aforementioned water supply plan and regionalizing service. If done properly, it is likely that regionalization would add more flexibility to meet water needs, and also benefit environmental resources. As the results of this study have indicated, water withdrawal locations in the watershed have differing levels of impact; some have more impact, other less, or no impact. Having the ability to shift pumping locations, times, and rates from areas of high impact to low impact at crucial times would benefit the sustainability of the Parker River waters resources.

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Acronyms and Conversions

ABF	Aquatic Base Flow
BWD	Byfield Water District
cfs	cubic feet per second
cfsm	cubic feet per second per square mile of drainage area
EOEA	Executive Office of Environmental Affairs
gpcd	gallons per capita day
GCC	Georgetown Country Club
GIS	Geographic Information System
GPD	gallons per day
GPS	Global Positioning System
GWD	Georgetown Water Department
IHA	Indicators of Hydrologic Alteration
MassGIS	Massachusetts Geographic Information System
MDEM	Massachusetts Department of Environmental Management
MDEP	Massachusetts Department of Environmental Protection
MDFW	Massachusetts Department of Fisheries and Wildlife
MWI	Massachusetts Watershed Initiative
MG	million gallons
MGD	million gallons per day
MGM	million gallons per month
MGY	million gallons per year
NPDES	National Pollutant Discharge Elimination System
PWSASR	Public Water Supply Annual Statistical Report
USGS	United States Geological Survey
WMA	Water Management Act

<u>Conversions</u>

1 MGD=1.547 cfs
1 acre= 43,560 square feet
1 mi^2= 640 acres

Glossary of Terms

Alluvium: Deposits of clay, silt, sand, gravel or other particulate rock material left by a river in a streambed, on a flood plain, delta, or at the base of a mountain.

Annual 7-day minimum flow: The lowest mean discharge for 7 consecutive days for a water year.

Aquifer: A geologic formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base flow: Sustained, low flow in a stream; ground-water discharge is the source of base flow in most places.

Bedrock: General term for solid rock that underlies soil or other unconsolidated material.

cfs (cubic feet per second) : The flow rate or discharge equal to one cubic foot (of water, usually) per second. This rate is equivalent to approximately 7.48 gallons per second. This is also referred to as a second-foot.

Consumptive Use: Water removed from the immediate aquatic environment through evaporation, transpiration, human consumption, agriculture, industry, etc.

Discharge: the volume of water that passes through a given cross section per unit time. Discharge is commonly measured in cubic feet per second (cfs) or cubic meters per second (cms). It is also referred to as *flow*.

Evapotranspiration: A collective term that includes water lost through evaporation from the soil and surface-water bodies and by plant transpiration.

Exceedence probability: hydrologically, the probability that an event selected at random will exceed a specified magnitude.

Flow Duration Curve: A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Gaging Station: A particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Ground water: In general, any water that exists beneath the land surface, but more commonly applied to water in fully saturated soils and geologic formations.

Hydrograph: a description of flow versus time or a description of stage versus time.

Hydrology: the study of water. Hydrology generally focuses on the distribution of water and interaction with the land surface and underlying soils and rocks.

Instream use: The use of water that does not require withdrawal or diversion from its natural watercourse; for example, the use of water for navigation, recreation, and support of fish and wildlife.

Interbasin Transfer: The physical transfer of water from one watershed to another.

Median: The middle or central value in a distribution of data ranked in order of magnitude. The median is also known as the 50th percentile.

Peak flow: the point of the hydrograph that has the highest flow.

Precipitation: Any or all forms of water particles that fall from the atmosphere, such as rain, snow, hail, and sleet.

Pulsing flow: the artificial increase and decrease of flow that typically follows a daily pattern.

Rating curve: the relationship between stage and discharge.

Reach: a segment of a stream channel.

Recharge: Water that infiltrates the ground and reaches the saturated zone.

Recurrence Interval: The average amount of time between events of a given magnitude. For example, there is a 1% chance that a 100- year flood will occur in any given year.

Reservoir: A manmade facility for the storage, regulation and controlled release of water.

Reservoir Surface Area: The surface area of a reservoir when filled to the normal pool or water level.

Runoff: That part of precipitation that flows toward the streams on the surface of the ground or within the ground. Runoff is composed of baseflow and surface runoff.

Run-of-River Operation: A reservoir is operated as a run-of-river facility when reservoir inflow instantaneously equals reservoir outflow. There is no change in the timing or magnitude of reservoir inflow or outflow.

Stormwater Discharge: Precipitation that does not infiltrate into the ground or evaporate due to impervious land surfaces but instead flows onto adjacent land or water areas and is routed into drain/sewer systems.

U.S. Geological Survey (USGS): The Federal Agency chartered in 1879 by congress to classify public lands, and to examine the geologic structure, mineral resources, and products of the national domain. As part of its mission, the USGS provides information and data on the Nation's rivers and streams that are useful for mitigation of hazards associated with floods and droughts.

Watershed: an area characterized by all direct runoff being conveyed to the same outlet. Similar terms include *basin*, *subwatershed*, *drainage basin*, *catchment*, and *catch basin*.

Water Year: The USGS typically reports surface water data in terms of a water year, which is the 12-month period of October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1946, is called the "1946 water year".

Wetland: An area that is regularly wet or flooded and has a water table that stands at or above the land surface for at least part of the year.

1 Introduction

The Parker River watershed, with a drainage area of 82 square miles, is a coastal river system located in the northeast corner of Massachusetts. The watershed is situated between the Merrimack River watershed to the north and the Ipswich River watershed to the south. The Parker River originates in the Town of Boxford and flows easterly for approximately 21 miles before emptying into Plum Island Sound, near the City of Newburyport. The mainstem Parker River has a drainage area of 32.6 square miles; 25 square miles comprise the freshwater portion, while the remainder is tidally influenced. Major tributaries to the tidal portion of the Parker River include the Mill River (drainage area of 18 square miles) and Little River (drainage area of 10.7 square miles). The Egypt and Rowley Rivers (total drainage area of 9.6 square miles), as well as the Plum Island and Eagle Hill Rivers (total drainage area of 12.0 square miles) empty into Plum Island Sound.

A previous statistical analysis, completed by the Massachusetts Department of Environmental Management (MDEM), of United States Geological Survey (USGS) streamflow data indicated that recent low flow conditions in the Parker River above the Byfield gaging station (in operation since October 1945) were lower than historic averages. The median value of the 7-day annual minimum flow[3] is 0.48 cfs for the period of record at the gage. Since 1993, the 7-day annual minimum flow ranged from 0.04 cfs to 0.16 cfs. These values were lower than the “drought” period of the 1960’s in which the 7-day annual minimum flow statistic was 0.26 cfs (MDEM 2001).

In addition, during portions of August and September of 1997 approximately 0.5 miles of the Parker River became desiccated in the area above Bailey Lane in the Town of Georgetown (PRCWA 2001). The summer of 1997 was particularly dry in terms of precipitation. The desiccated reaches were located downstream of several municipal water supply wells operated by Georgetown. During 1997 and several other dry summers, streamflows recorded at the Byfield USGS gage have exhibited prolonged periods of relatively low levels as well. Similar conditions have been documented in the Ipswich River watershed, where portions of the river dried in 1995, 1997, 1999, and 2002 (Ipswich River Watershed Association 2003).

Maintaining appropriate flows in river systems is important to sustain aquatic biota (i.e., fish, amphibians, macroinvertebrates and plants) and the entire river ecosystem as a whole. Over time, the aquatic biota within the Parker River have adapted to the natural flow regime. In particular, aquatic biota have adapted to tolerate the critical summer low flow period, which typically occurs during the July-September timeframe. With increasing pressures from human development, the magnitude of these summer low flows can diminish and persist for much longer periods than would otherwise occur naturally. As a result, habitat for aquatic biota can diminish severally, which can lead to mortality. In addition, unnatural low flow conditions can result in water quality degradation (higher temperatures, lower dissolved oxygen levels, water odor).

The Executive Office of Environmental Affairs (EOEA) Watershed Initiative and the Parker River Watershed Team commissioned this study to investigate the recurring low flow events in the Parker River. To facilitate this investigation, the following study objectives were identified.

[3] The lowest mean discharge for 7 consecutive days during a given year.

- Determine overall long-term trends for several key hydrologic statistics for the Water Year[4] (WY) 1946-2002 period of streamflow record at the Byfield USGS gage.

- Compare these key hydrologic statistics for the WY 1946-89 and WY 1990-2002 periods.

- Estimate hydrologic statistics for a completely unregulated/natural flow regime at the Byfield USGS streamflow gage.

- Examine the major hydrologic components of the watershed, upstream of the Byfield USGS streamflow gage, for historic and recent dry years.

- Identify areas of streamflow loss or gain along the Parker River above the Byfield USGS streamflow gage.

- Evaluate recent annual and seasonal trends of registered and permitted water withdrawals in the Parker River watershed above the Byfield USGS streamflow gage.

- Evaluate historic trends in land use and wetland area changes, as well as beaver population dynamics within the watershed above the Byfield USGS streamflow gage.

This study attempts to confirm the increased occurrence of unusually low flow events in the Parker River during recent times. Once confirmed, the study evaluates potential causes of these low flow conditions, and attempts to determine their relative magnitude of impact. The potential causes evaluated include the following:

- Natural variations in the hydrologic cycle (i.e., reduced and/or changes in the timing precipitation);
- Increasing water withdrawals for public water supply and industrial uses;
- Increased urban development/growth within the study area; and
- Increased beaver activity within the study area.

Although several aspects of the entire watershed are discussed in detail within this report, the principal study area was focused on that portion of the watershed located above the Byfield USGS streamflow gage. The Byfield USGS streamflow gage has a drainage area of 21.3 square miles, and is located approximately 1.6 miles above the tidal influence of the Atlantic Ocean.

The authors are very grateful to the numerous individuals who provided information or comments during the study. These individuals include Victoria Gartland (MDEM), Linda Marler (MDEM), Russ Cohen (Massachusetts Riverways), Steve Asen (MDEM), Richard Tomczyk (MDEP), Kellie O'Keefe (MDEP), Ron Stelline (MDEP), Margaret Kearns (Massachusetts Riverways), Alan Macintosh (Merrimack Valley Planning Commission), Peter Phippen (Merrimack Valley Planning Commission), Paul Colby (Byfield Water District), Wilfred Kelly (Georgetown Water Department), Don Bade (Parker River Clean Water Association), Dave Mountain (Parker River Clean Water Association), Rob Stevenson (Parker River Clean Water Association), Kerry Mackin (Ipswich River Watershed Association), Paul Thompson (GCC), Jeff Gudaitis (GCC), and Chrissie Henner (MDFW).

[4] The USGS typically reports surface water data in terms of a water year, which is the 12-month period of October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year beginning October 1, 1945 and ending September 30, 1946, is called the "1946 water year". For purposes of comparison, precipitation data was also analyzed by water year as well.

2 Parker River Watershed Description and Physical Characteristics

The purpose of this section is to provide an overview of the Parker River watershed characteristics and to describe various components of the river's course. The entire watershed is described in the following sections; however, the major focus of this study was the watershed area located above the Byfield USGS streamflow gage.

2.1 General Overview of the Parker River Watershed

The Parker River watershed is a coastal river system located in the northeast corner of Massachusetts. As shown in Figure 2.1-1, the watershed is situated between the Merrimack River watershed to the north and the Ipswich River watershed to the south. The Parker River is the largest tributary to Plum Island Sound, and originates in a natural wetland, just east of Main Street in West Boxford, at the confluence of two unnamed streams. From its origins, the Parker River flows northeasterly and then gradually turns east flowing into the Atlantic Ocean at Plum Island Sound. The Parker River National Wildlife Refuge is located at the mouth of the Parker River. This refuge consists of 4,650 acres of sand dunes, salt marsh, freshwater marsh, and glacial upland. Also included in the refuge are six miles of ocean beach along the eastern side of Plum Island (MDEP, 2001).

The river flows its entire length of approximately 21 miles through rolling, rural landscape. The entire Parker River watershed drains a total of approximately 82 square miles. The major tributaries to the Parker River include the Mill River, Ox Pasture Brook, Little River, Penn Brook, Jackman Brook, Wheeler Brook, Bachelder Brook, Beaver Brook, and the Rowley River. There are a total of 14 lakes and ponds in the entire Parker River watershed, which combine to cover approximately 295 acres of the watershed. The most prominent waterbodies in the watershed above the Byfield USGS gage are Baldpate Pond (55 acres), Sperrys Pond (6 acres), Rock Pond (50 acres), Pentucket Pond (85 acres), Little Crane Pond (5 acres), and Crane Pond (19 acres) (EOEA, 2001).

At the outlet of Pentucket Pond in Georgetown, there is small dam that controls water level at the pond. There are an additional six low-head dams located on the mainstem of the Parker River, all in the Town of Newbury (Byfield). These include two dams at River Street, due west of Main Street in the village of Byfield; two dams near Main Street in the village of Byfield; one dam northwest of Larkin Road (east of Interstate 95); and the most downstream dam on the Parker River is located at the Central Street crossing in Newbury. All dams are equipped with fish passage devices to allow anadromous fish, such as alewife, to migrate upstream to spawn in the Parker River headwaters. All of the dams operate in a run-of-river mode (i.e., under normal conditions the dams are not operated to artificially manipulate pond and stream levels).

2.2 Detailed Description of the Parker River Course

The headwaters of the Parker River are formed near Sperrys Pond in Boxford, as shown in Figure 2.2-1. From the outlet of Sperrys Pond, the headwater stream flows south for 0.7 miles through a moderate gradient reach. At this point, the mainstem of the Parker River originates at the confluence of the headwater stream and an unnamed tributary just east of Main Street in Boxford. The river then flows northeasterly approximately 3.5 miles to Rock Pond via a series of low-lying wetland complexes. Approximately 1 mile upstream of Rock Pond, the Town of Georgetown maintains a series of groundwater wells for public water supply purposes. A 0.3 mile reach of the Parker River connects Rock Pond (50 acres) and Pentucket Pond (85 acres). G-Town Produce maintains a surface water withdrawal from Rock Pond.

At Pentucket Pond Dam, the Parker River flows 0.15 miles where it is joined by a tributary-Penn Brook (Baldpate Pond is located at the headwaters of Penn Brook). From this point, the river turns sharply to the north, flowing 2.2 miles through a low gradient reach to Crane Pond (19 acres). Georgetown Sand and Gravel maintains a surface water withdrawal near the river slightly less than halfway between Pentucket and Crane Ponds. At Crane Pond, the river turns sharply to the east flowing 2.2 miles to the Byfield USGS streamflow gage, just west of the Route 95 crossing. Just downstream of Crane Pond, the Beaver Brook tributary flows into the Parker River. Approximately 0.3 miles upstream of the USGS gage the river gradient increases somewhat near the dams located near River and Main Streets in Newbury. In addition, the Town of Newbury (Byfield) maintains a groundwater withdrawal for public water supply approximately 0.8 miles upstream of the Byfield USGS streamflow gage. This withdrawal is located just north of the Parker River, near Forest Street.

Newbury (Byfield) also maintains a groundwater withdrawal for public water supply approximately 0.5 miles below the USGS gage, near Larkin Road. A dam is also located along this segment of the Parker River as well. From this area, the river flows 0.9 miles to the dam located at the Central Street crossing in Newbury. Halfway between the USGS gage and the Central Street dam, Wheeler Brook and Jackman Brook join the Parker River as tributaries. The tidal reach of the Parker River begins just below the Central Street dam. From this point, the Parker River meanders 6.0 miles through salt marsh, where it meets the Mill River. The Mill River is fed by Bachelder and Ox Pasture Brooks. Approximately 1.5 miles downstream from this point the Little River tributary joins the Parker River. The Parker then flows 2.0 miles to reach Plum Island Sound. The Rowley River also empties into Plum Island Sound approximately 2.0 miles to the south of the Parker River mouth.

2.3 Basin Topography and River Slope

Shown in Figure 2.3-1 is a topographic relief map of the Parker River watershed. The Atlantic coastal plain is typified by relatively low relief. The surficial landscape throughout the watershed is characterized by an irregular terrain comprised of numerous small hills and narrow ridges separated by low-lying areas in many places containing wetlands and ponds. Extensive salt marshes interlaced with tidal streams and creeks comprise the easterly third of the watershed. The highest terrain, with elevations reaching approximately 300 feet, is located in the headwaters of the watershed east of Sperrys Pond. The highest point within the watershed is Baldpate Hill at elevation 353 feet located south of Rock and Pentucket Ponds. The Parker River elevation decreases from approximately 120 feet near its origins at the confluence of two unnamed tributaries just east of Main Street in Boxford, to sea level at its mouth. The average slope for the river is 5.7 feet/mile. The river gradient is controlled by several wetland complexes, natural ponds, and man-made dams that create slack water conditions.

2.4 Surficial Geology

A surficial geology map of the Parker River watershed is shown in Figure 2.4-1. Past glaciation is the primary mechanism responsible for the landforms in the watershed. A succession of glacial ice advances and retreats deposited detritus on an eroded bedrock surface. The deposition of the detritus occurred directly from the ice sheet or by meltwater from a retreating glacial ice sheet. The major landforms resulting from the glacial activity include drumlins, eskers, and kame terraces.

Glacial till and bedrock cover approximately 33% of the watershed. Bedrock outcroppings in the watershed are common at elevation; however, glacial till typically covers the bedrock surface in these areas. The till deposits, typically less than 20 feet thick, consist of an unsorted mixture of clay, silt, sand, and gravel.

In the easterly portion of the watershed, fine grained marine sediments, resulting from the retreat of the last glaciation, are prevalent in low-lying areas. These deposits typically consist of marine sands overlying marine clays and silts. Deposition of these sediments took place when the sea level encroached upon the present day mainland. Recent deposits of beach and dune sand blanket the Plum Island area. Documentation indicates that this area formed as a mainland beach line after the glacial episodes. During its formation, the sea level was lower than present, and subsequently began to rise over time, resulting in the formation of Plum Island. These fine grained deposits and alluvium comprise 11% and 19% of watershed area, respectively.

In the western portion of the watershed, low-lying areas are covered by glacial contact and meltwater deposits. These deposits typically consist of well sorted fine to coarse grained sediments. In locations where these deposits form significant permeable sand and gravel layers, groundwater yields of 100 gpm are available (Metcalf & Eddy, 1973). Overall, sand and gravel deposits blanket 37% of the watershed.

2.5 Land Use

A land use map of the Parker River watershed is shown in Figure 2.5-1, and was obtained from MassGIS. Table 2.5-1 shows a detailed breakdown of land use within the watershed. Based on 1999 land use mapping, 44.0% of the watershed is forested. The next largest land use is residential (16.9%), followed by salt wetland (16.6%).

Table 2.5-1: Land Use in the Entire Parker River Watershed for 1999

Land Use Type	Percent Breakdown	Definition
Forest	44.0%	Forest
Residential	16.9%	Residential
Salt Wetland	16.6%	Salt marsh
Cropland	5.5%	Intensive agriculture
Open Land	4.4%	Abandoned agriculture; power lines; areas of no vegetation
Wetland	3.4%	Nonforested freshwater wetland
Pasture	2.0%	Extensive agriculture
Recreation	1.7%	Golf; tennis; playgrounds; skiing; stadiums; racetracks; fairgrounds; drive-ins; beaches; marinas; swimming pools
Industrial	1.2%	Light & heavy industry
Transportation	1.1%	Airports; docks; divided highway; freight; storage; railroads
Urban Open	1.0%	Parks; cemeteries; public & institutional greenspace; vacant undeveloped land
Water	0.8%	Fresh water; coastal embayment
Commercial	0.7%	General urban; shopping center
Mining	0.3%	Sand; gravel & rock
Woody Perennial	0.3%	Orchard; nursery; cranberry bog
Waste Disposal	0.2%	Landfills; sewage lagoons

The watershed encompasses all or part of 9 municipalities, which support a population of approximately 95,000 people. Table 2.5-2 illustrates Year 2000 census totals for each entire community, as well as the percent of each community's land area within the watershed (Massachusetts Watershed Initiative, 2002). The major population centers within the watershed are concentrated in Boxford, Georgetown, Newbury (Byfield), and Rowley.

Table 2.5-2: Population for Municipalities in Located in All or Part of the Parker River Watershed

Community	Percent of Community in Watershed	Total Population (2000)
Boxford	24.6%	7,921
Georgetown	99.8%	7,377
Groveland	38.5%	6,038
Ipswich	38.6%	12,897
Newbury	88.8%	6,717
Newburyport	45.8%	17,189
North Andover	0.8%	27,202
Rowley	94.9%	5,500
West Newbury	26.6%	4,179

Figure 2.1-1: General Locale of the Parker River Watershed

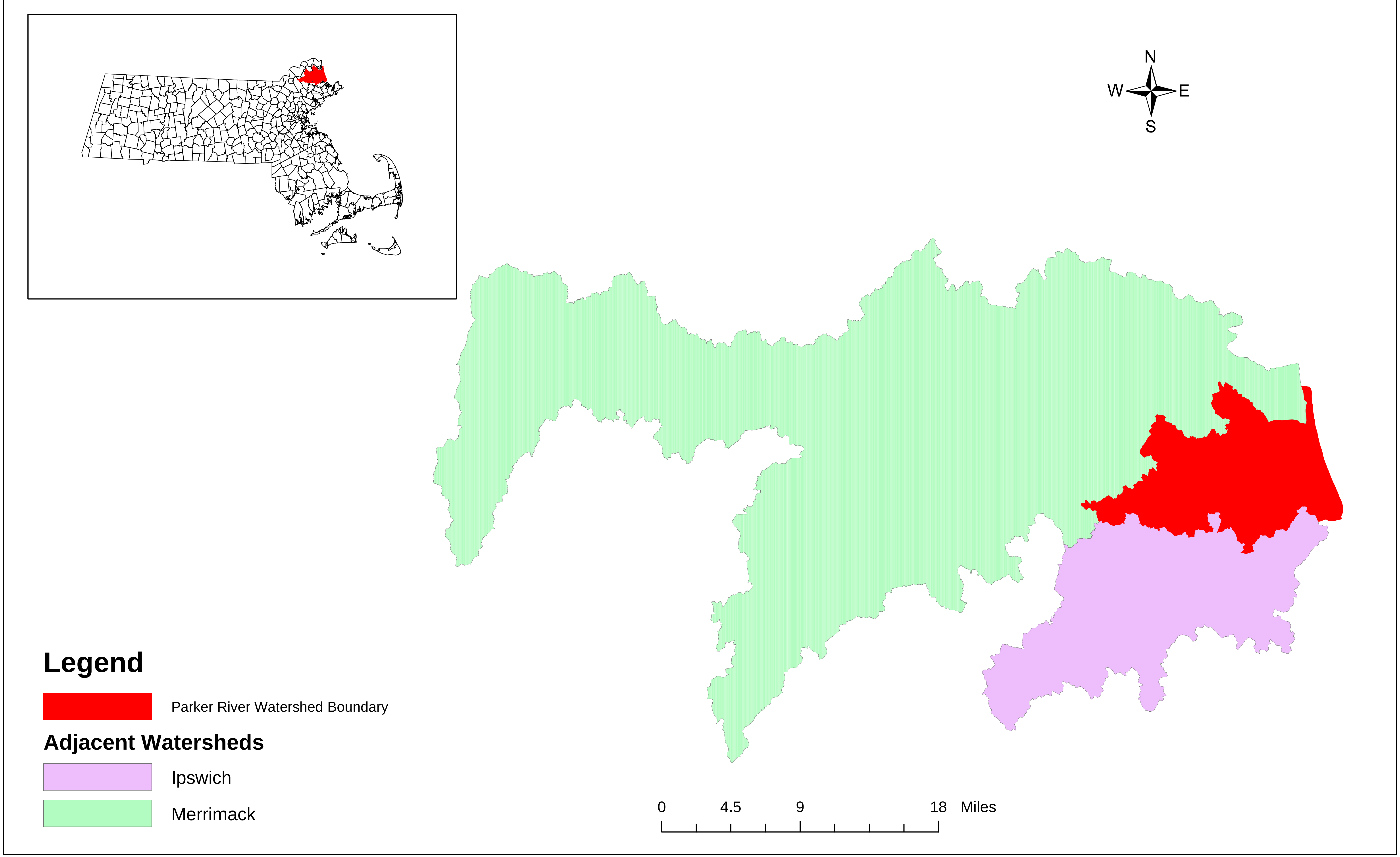


Figure 2.2-1: Parker River Watershed Map

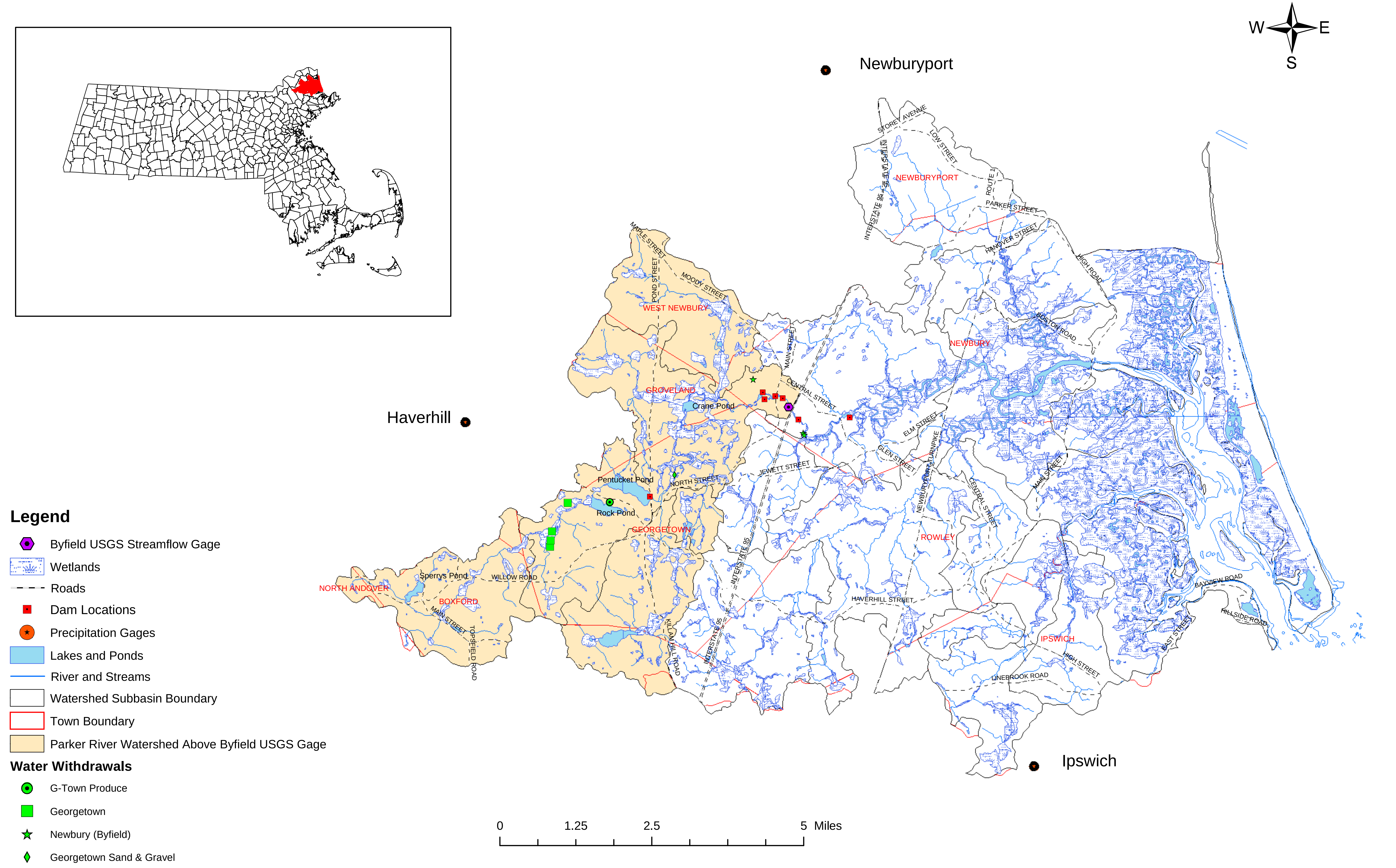


Figure 2.3-1: Topographic Map of the Parker River Watershed

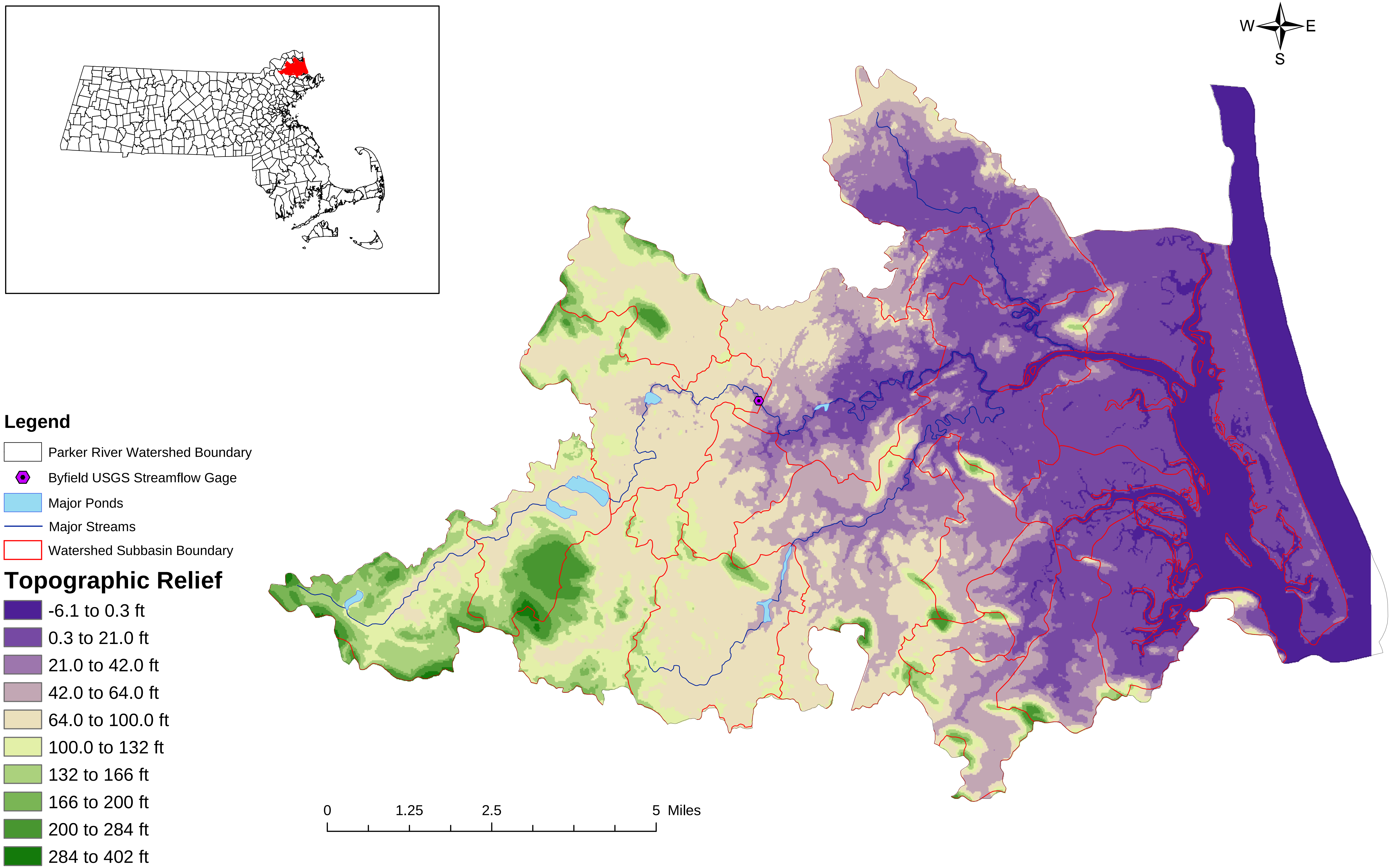


Figure 2.4-1: Surficial Geology of the Parker River Watershed

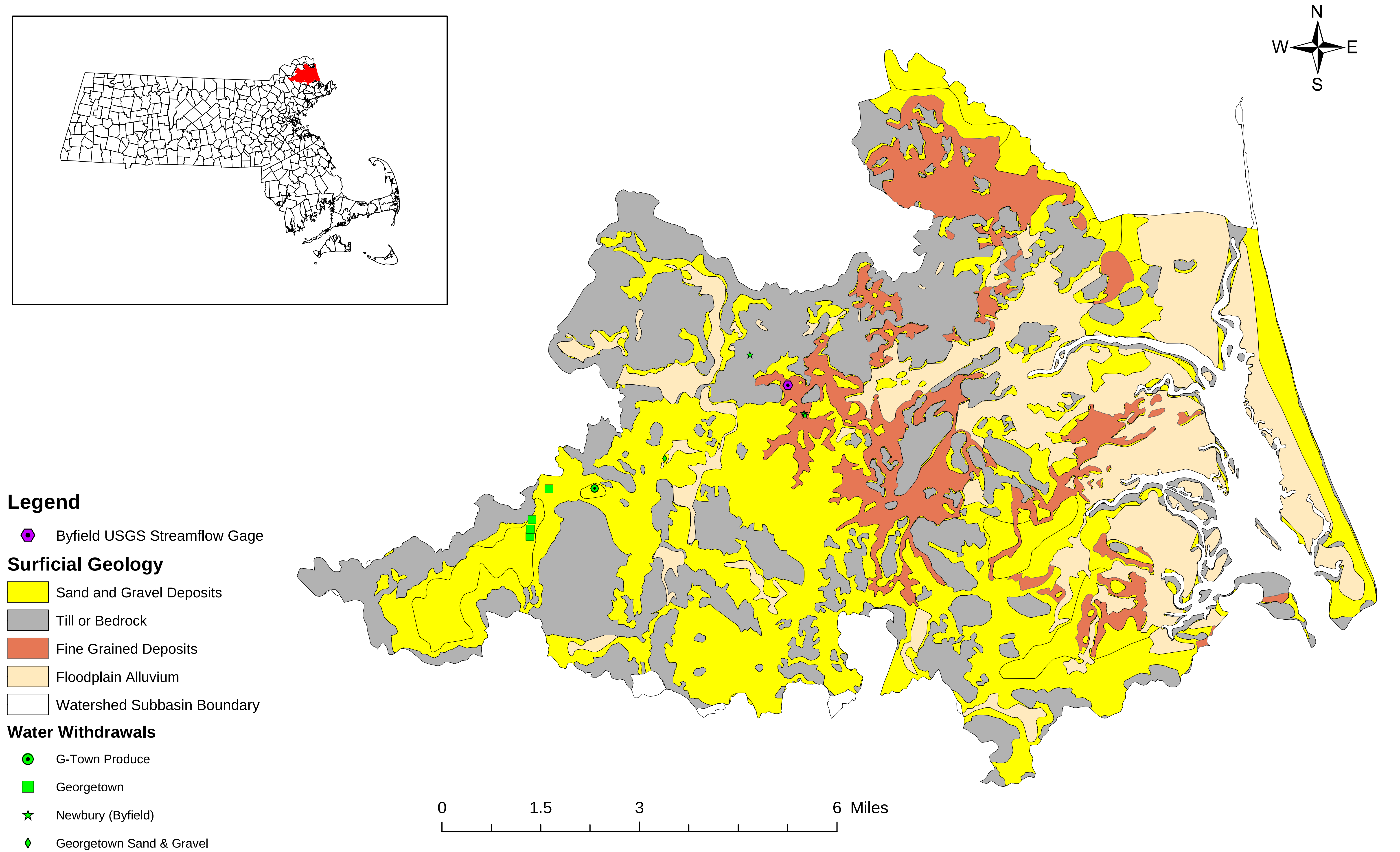
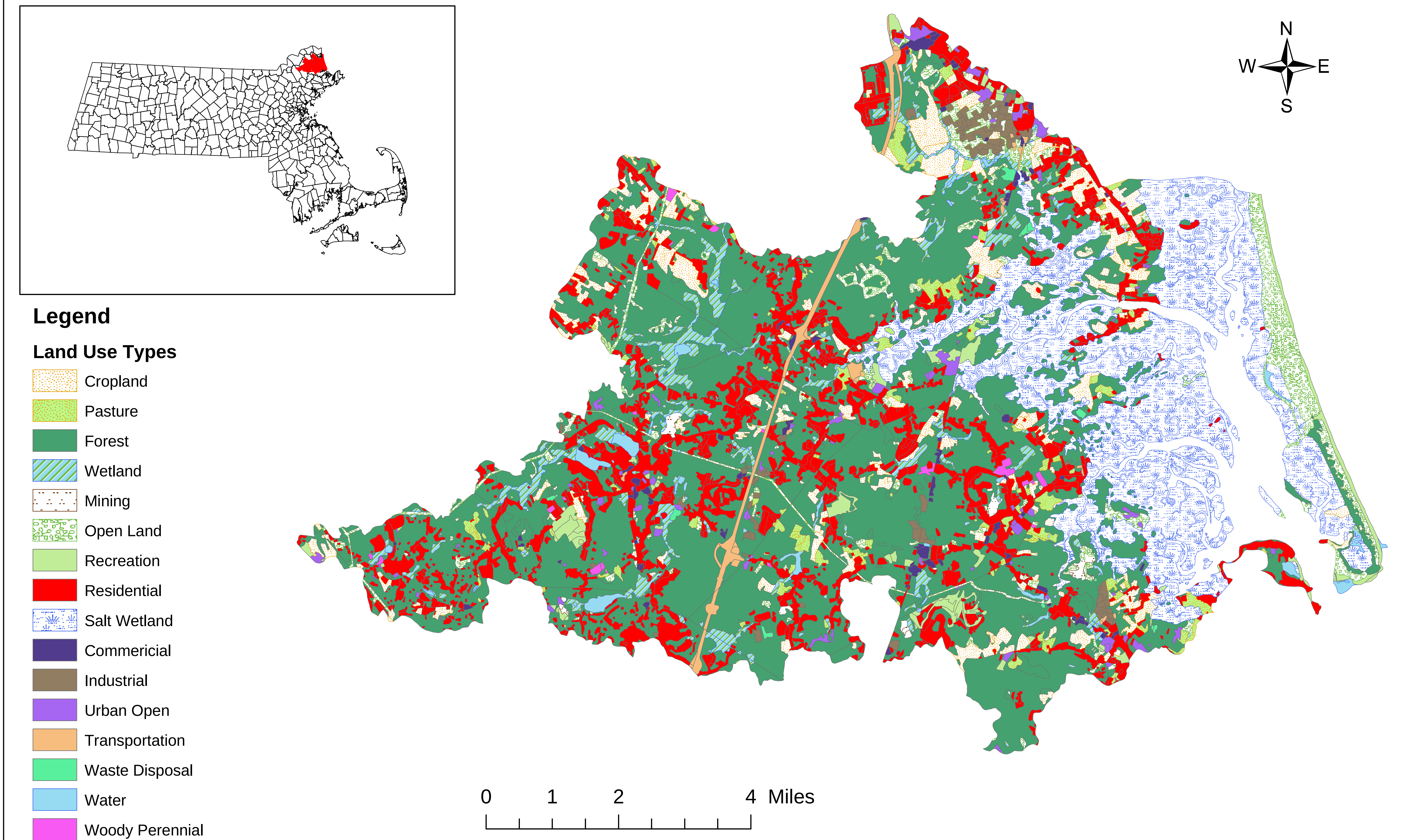


Figure 2.5-1: Land Use within the Parker River Watershed



3 Evaluation of the Parker River Hydrologic Regime

In this section, we analyze the historic and recent trends of the Parker River hydrologic (i.e., precipitation, streamflow, groundwater) regime using several methods. Parker River streamflow was investigated using the Byfield USGS gage, which has a drainage area of 21.3 square miles and a period of record beginning in WY 1946 and continuing through to the present. This study was focused on the watershed area upstream of the Byfield USGS gage. The main relevance of selecting the Byfield USGS gage as the downstream limit of the study area was that the data generated from it helped to investigate the flow conditions.

In general, the lowest flows typically occur in the Parker River during the late summer period, when monthly median streamflow values range from 2.6 cfs in August and 2.2 cfs in September. Fall precipitation typically recharges streamflows, with monthly median streamflow during the fall/winter period ranging from 5.5 cfs in October to 41.0 cfs in February. Spring snowmelt during March/early April typically produces annual peak streamflows. The monthly median streamflows in the Parker River are approximately 68 cfs during both March and April. With the onset of the growing season and drier weather, streamflow begins to subside in late spring/early summer when monthly median flows for May, June, and July are 41.0 cfs, 17.0 cfs, and 4.6 cfs, respectively.

Under natural conditions, groundwater levels typically follow the normal seasonal pattern of streamflow (highest in the spring, lowest in the late summer). Groundwater levels were examined at two USGS monitoring wells to determine the degree of long-term and short-term aquifer depletion within the study area. The monitoring wells examined below are in proximity to several of the water withdrawals examined; however, they are not close enough to be of use in examining the impacts of these withdrawals.

Precipitation patterns were analyzed to determine their relative impact on the timing and magnitude of streamflow and groundwater levels within the study area.

3.1 Indicators of Hydrologic Alteration (IHA) Analysis

Hydrologic regimes are important in determining the composition, structure, and function of aquatic, wetland, and riparian ecosystems. Human disturbance can result in changes to the natural hydrologic regimes of rivers and streams. To identify the impact of human disturbance on a hydrologic regime, the Nature Conservancy developed the Indicators of Hydrologic Alteration (IHA) (Richter, B., Baumgartner, J., Powell, J., Braun, D. 1996). The IHA method, which makes use of average daily flow data, analyzes 32 separate parameters to evaluate potential alterations to a hydrologic regime. The 32 flow parameters evaluate the timing, duration, frequency, magnitude and rate of change of flow conditions. The IHA method is used to assess hydrologic changes associated with activities such as dam operations, flow diversion, groundwater pumping, or intensive land-use conversion.

IHA allows for an analysis of the overall trends in streamflow for a gage's period of record. This particular technique is useful for analyzing the gradual, long-term accumulation of human impacts rather than a single impact, such as construction of a major regulating dam. In addition, the IHA technique allows for a comparison of pre-impact and post-impact hydrologic regimes, such as before and after the construction of a major regulating dam.

Shown in Table 3.1-1 is a summary of the grouping, hydrologic parameters, and ecosystem influences. This table was taken directly from the IHA manual (Richter, et al 1996) and is not specific to the Parker

River watershed. The ecosystem influences provide general information on what resources may be affected by changes in certain hydrologic variables. No site-specific ecological information on the Parker River watershed or its tributaries has been collected as part of this study.

Table 3.1-1: Hydrologic Parameters and their Characteristics used in the IHA Analysis

IHA Statistics Group	Hydrologic Parameters	Ecosystem Influences
Group 1: Magnitude of Monthly Water Conditions	Mean value for each calendar month	• Habitat availability for aquatic organisms. • Soil moisture availability for plants. • Availability of flood/cover for fur-bearing animals. • Reliability of water supplies for terrestrial animals. • Access by predators to nesting sites. • Influences water temperature, oxygen, photosynthesis in water column.
Group 2: Magnitude and Duration of Annual Extreme Water Conditions	Annual 1-day minimum Annual minimum, 3-day means Annual minimum, 7-day means Annual minimum, 30-day means Annual minimum, 90-day means Annual 1-day maximum Annual maximum, 3-day means Annual maximum, 7-day means Annual maximum, 30-day means Annual maximum, 90-day means Base flow	• Balance of competitive and stress-tolerant organisms. • Creation of sites for plant colonization. • Structuring of aquatic ecosystems by abiotic vs. biotic factors. • Structuring of river channel morphology and physical habitat conditions. • Soil moisture stress in plants. • Dehydration in animals. • Anaerobic stress in plants. • Volume of nutrient exchanges between rivers and floodplains. • Duration of stressful conditions (i.e., low oxygen & concentrated chemicals in aquatic environments.) • Distribution of plant communities in lakes, ponds, floodplains. • Duration of high flows for waste disposal, aeration of spawning beds in channel sediments.
Group 3: Timing of Annual Extreme Water Conditions	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum	• Compatibility with life cycles of organisms. • Predictability/avoidability of stress for organisms. • Access to special habitats during reproduction or to avoid predation. • Spawning cues for migratory fish . • Evolution of life history strategies, behavioral mechanisms.
Group 4: Frequency and Duration of High and Low Pulses	No. of low pulses within each year Mean duration of low pulses within each year No. of high pulses within each year Mean duration of high pulses within each year	• Frequency and magnitude of soil moisture stress for plants. • Frequency and duration of anaerobic stress for plants. • Availability of floodplain habitats for aquatic organisms. • Nutrient and organic matter exchanges between river and floodplain. • Soil mineral availability. • Access for waterbirds to feeding, resting, reproduction sites. • Influences bedload transport, channel sediment textures, & duration of substrate disturbance (high pulses).
Group 5: Rate and Frequency of Water Conditions Change	Means of all positive differences between consecutive daily values (Rise Rate)	• Drought stress on plants (falling levels). • Entrapment of organisms on islands, floodplains (rising levels).

IHA Statistics Group	Hydrologic Parameters	Ecosystem Influences
	Means of all negative differences between consecutive daily values (Fall Rate) Number of hydrological reversals.	• Desiccation stress on low-mobility streamedge (varial zone) organisms.

The rationale underlying the components of these five major groupings of hydrologic characteristics is described below (Richter et. al. 1996).

<u>Group 1-Magnitude:</u> This group includes 12 parameters, each of which measures the central tendency (mean) of the daily water conditions for a given month. The monthly mean of the daily water conditions describes normal daily conditions for the month.

<u>Group 2-Magnitude and Duration of Annual Extreme Conditions:</u> The 11 parameters in this group measure the magnitude of extreme (minimum and maximum) annual water conditions of various duration, ranging from daily to seasonal. The durations used include the 1-day, 3-day, 7-day (weekly), 30-day (monthly) and 90-day (seasonal) extremes. For a given year, the 1-day maximum (or minimum) is represented by the highest (or lowest) single daily value occurring during the year. The multi-day maximum (or minimum) is represented by the highest (or lowest) multi-day average value occurring during the year. The high and low water extremes of various durations provide measures of environmental stress and disturbance during the year. Conversely, such extremes may be necessary triggers for the reproduction of certain species. Base flow is defined as the 7-day minimum flow divided by the mean annual flow.

<u>Group 3-Timing of Annual Extreme Conditions:</u> This group includes two parameters, one measuring the Julian date of the 1-day annual minimum water condition and the other measuring the Julian date of the 1-day maximum water condition. The timing of the highest and lowest water conditions within annual cycles provides another measure of environmental disturbance. Key life-cycle phases, such as successful reproduction, may be intimately linked to the timing of annual extremes. Although not calculated as part of the IHA analysis, it is expected that the timing of occurrence for other annual extreme water statistics (i.e., 3-day annual minimum, etc.) would mimic the trends seem in the 1-day maximum and minimum flow statistics.

<u>Group 4-Frequency and Duration of High and Low Pulses:</u> The four parameters in this group include two that measure the number of annual occurrences during which the magnitude of the water condition exceeds an upper threshold or remains below a lower threshold, respectively, and two that measure the mean duration of such high and low pulses. Hydrologic pulses are defined as those periods within a year in which the daily mean water condition either rises above the 75^{th} percentile (high pulse) or drops below the 25^{th} percentile (low pulse) of all daily values for the period of interest.

<u>Group 5-Rate and Frequency of Change in Conditions:</u> The three parameters in this group measure the number and mean rate of both positive and negative changes in water conditions from one day to the next.

3.1.1 Evaluation of Long Term Hydrologic Trends at the Byfield USGS Gage (IHA Analysis)

The IHA analysis was conducted on the Byfield USGS gage on the Parker River. IHA allows for an analysis of the overall trends in streamflow for a gage's period of record. Graphs of the IHA parameters are produced together with a linear regression analysis of the data. The slope of the regression line provides an indication as to whether the trend showed a long-term increase (positive slope) or decrease (negative slope) in flow over the respective period of record. Flow data sets of sufficient length are needed to alleviate skewing of the results that might occur from outliers.

The results of the 32 flow parameters generated from the analysis are described below. The following figures were developed and are contained in Appendix A of this report:

Group 1: Figures A-1 through A-12: January through December mean monthly flows;
Group 2: Figure A-13: Base Flow
Figures A-14 through A-18: Annual minimum 1-day, 3-day, 7-day, 30-day and 90-day, respectively;
Figures A-19 through A-23: Annual maximum 1-day, 3-day, 7-day, 30-day, and 90-day, respectively;
Group 3: Figures A-24 through A-25: Julian date of each annual 1-day maximum and minimum flow, respectively;
Group 4: Figures A-26 through A-27: Number of low and high pulses each year, respectively;
Figures A-28 through A-29: Duration of low and high pulses within each year, respectively;
Group 5: Figures A-30 through A-31: Rate of flow rise and fall, respectively; and
Figure A-32: Number of reversals.

The results of the IHA analysis are summarized below. Interpretations of the results are discussed further in Section 7-Discussion and Conclusions.

The Group 1 parameters show a slightly decreasing trend in the magnitude of mean monthly flow for January, March, August, and September. Mean monthly flows for February, April, May, and July show a very slight increase, while the months of June, October, November, and December experience a more moderate increase in mean monthly flow over time.

The base flow, annual minimum 1-day, 3-day, and 7-day, 30-day, and 90-day parameters show an overall decrease in flow magnitude. In addition, during the 1993-99 period each of these parameters show a prolonged low flow period relative to the overall period of analysis. The annual maximum 1-day, 3-day, 7-day parameters show fairly significant increases in flow magnitude, while the annual maximum 30-day and 90-day show a more moderate increase magnitude over time.

The date of occurrence for the 1-day maximum flow shows a slight increase, while the date of occurrence for the 1-day minimum flow is essentially stagnant. Although not calculated as part of the IHA analysis, it is expected that changes in the date of occurrence for other annual extreme water statistics (i.e., 3-day annual minimum, etc.) would mimic the trends seem in the 1-day maximum and minimum flow statistics.

The number of low pulses shows a moderately increasing trend over time, while high pulses show a very slight increase. In terms of duration, low pulses exhibit a moderately decreasing trend; high pulses show a very slight increasing trend.

The rise rate parameter shows a moderately increasing trend with time, while the fall rate parameter exhibits a slightly increasing trend. In addition, the number of reversals increases slightly over the period of analysis.

Based on this portion of the IHA analysis, the most significant long-terms trends exhibited at the Byfield USGS gage appear to be within the Group 2 parameters. The base flow, annual minimum 1-day, 3-day, 7-day parameters exhibit fairly significant decreasing trends, while the annual maximum 1-day, 3-day, 7-day parameters show an increasing trend over the period of analysis. Also, the streamflow rise and fall rate parameters (Group 4) show significant increasing trends.

3.1.2 Evaluation of Pre- and Post-Impact Analysis at the Byfield USGS Gage (IHA Analysis)

This portion of the IHA analysis was conducted on the Byfield USGS Gage using the following periods of record: WY 1946-89 (Pre-Impact) and WY 1990-2002 (Post-Impact). This division between the pre- and post-impact periods was selected, since low flows in the Parker River appear to be substantially lower during WY 1990-2002. This characteristic can be observed in the graphs produced in the preceding section, as well as the previous analysis conducted by MDEM (MDEM 2001). Specifically, the base flow, 1-day, 3-day, and 7-day annual minimum (see Figures A-13 through A-17) graphs show a repeated pattern of unusually low magnitudes during the 1990-2002 period, compared to the remaining period of record.

The results of this IHA analysis reflect the pre- and post-impact flow parameters; however, these same parameters will also reflect the cumulative effect of other disturbances in the watershed such as dams, land use changes, etc. Natural phenomena such as precipitation patterns/totals also influence river flow patterns.

The pre- and post-impact mean annual flow was computed for the Byfield USGS gage to determine if there was approximately the same volume of water for both time periods. Similarly, the same exercise was applied to the long-term precipitation record. If the pre- or post-impact period had a much higher or lower mean annual flow then the IHA results could be skewed. However, as shown in Table 3.1.2-1 the mean annual flow is essentially the same for the pre- and post impact periods of record. It is interesting to note precipitation during the WY 1990-2002 period is higher compared to the WY 1946-89 period.

Table 3.1.2-1 Comparison of Mean Annual Flow at the Byfield USGS Gage and Annual Average Precipitation

Period of Record	Mean Annual Flow (cfs) at Byfield USGS Gage	Annual Average Precipitation (in)
WY 1946-1989	36.98 cfs	44.9 in
WY 1990-2002	36.96 cfs	46.8 in
% Difference relative to pre-impact period	-0.05%	4.3%

The IHA program can be operated in various modes. For purposes of evaluating pre- and post-impact analysis the "non-parametric" option was selected. In this option, for each IHA parameter, and for both the pre- and post-impact periods, the median, 25th, and 75th percentile values are calculated. For each graph, the median, 25th, and 75th percentile is shown for both pre- and post-impact conditions. The following figures were developed and are contained in Appendix B of this report:

Group 1: Figures B-1 through B-12: January through December mean monthly flows;
Group 2: Figure B-13: Base Flow
Figures B-14 through B-18: Annual minimum 1-day, 3-day, 7-day, 30-day and 90-day, respectively;
Figures B-19 through B-23: Annual maximum 1-day, 3-day, 7-day, 30-day, and 90-day, respectively;
Group 3: Figures B-24 through B-25: Julian date of each annual 1-day maximum and minimum flow, respectively;
Group 4: Figures B-26 through B-27: Number of low and high pulses each year, respectively;
Figures B-28 through B-29: Duration of low and high pulses within each year, respectively;
Group 5: Figures B-30 through B-31: Rate of flow rise and fall, respectively; and
Figure B-32: Number of reversals.

Summary results as shown in Table 3.1.2-2. Columns 1 and 2 display the median (i.e., the 50th percentile) for each of the two periods. Columns 3 and 4 display the coefficient of dispersion for each period. This is defined as (75th percentile-25th percentile/50th percentile). Columns 5 and 6 show the deviation of the post impact period from the pre-impact period. This is defined as deviation factor= [(post-impact value)-(pre-impact value)/(pre-impact value). This deviation is shown both for the median and for the coefficient of dispersion. Columns 7 and 8 calculate a "significance count" for the deviation values. To calculate this, the IHA program randomly shuffled all years of input data and recalculated (fictitious) pre- and post impact medians and coefficients of dispersion 1,000 times. The significance count reported in this table is the fraction of trials for which the deviations between the medians or coefficients of dispersion were less than that for the real case (i.e., if the real case produces the largest deviation of all the trials, the significance count = 1.0. If the real case deviation is greater than only 30% of the randomized trials, the significance count = 0.30.)

In reviewing the Group 1 results, the median value of the mean monthly flows for June (40%), July (55%), August (80%), and September (22%) are significantly lower during the post-impact period compared to the pre-impact period. The median value of the October mean monthly flow increases 53%; however, it is important to consider that during October 1996 the highest recorded daily flow occurred (858 cfs) in response to a significant precipitation event. In addition, the October 1996 mean monthly flow was 186 cfs, compared to a mean monthly flow of 15.7 cfs for the entire period of record. December (8%), January (25%), and May (8%) show modest increases in the median value of the mean monthly flow during the post-impact period. The median value of mean monthly flows during November (4%), February (12%), March (17%), and April (4%) exhibit modest decreases during the post-impact period.

The Group 2 parameters show that the post-impact median value of the base flow, 1-day, 3-day, 7-day, 30-day, and 90-day annual minimum flows are significantly lower than pre-impact, by as much as 86%, 85%, 85%, 86%, 81%, and 68%, respectively. Although the percentages are high, the net difference in flow is relatively minimal. However, during low flow periods even a very small reduction in flow can have disproportionately high adverse impacts on aquatic biota. There is a modest change between the median value of the pre- and post-impact 1-day, 3-day, 7-day, 30-day, and 90-day annual maximum flows. The percent reduction in post-impact flow for the 1-day, 3-day, 7-day, 30-day, and 90-day annual maximum flows, when compared to pre-impact flow is 17%, 19%, 21%, 12%, and 6%, respectively.

The timing of the annual maximum and minimum flows also changed slightly between pre and post-impact conditions. The pre and post-impact annual minimum flows occurred on September 20th and September 4th, respectively, a shift of approximately 16 days earlier. A shift in the timing of the maximum flow occurred. The average pre- and post-impact annual maximum flows occurred on March 16th and March 29th, respectively, a shift of approximately 13 days later.

The low pulse count and duration were similar between pre- and post-impact conditions. The high pulse count increased moderately during post-impact conditions, and the high pulse duration decreased moderately as well.

The rate of rise and fall remained stagnant, and the number of reversals increased between the pre- and post-impact periods.

Table 3.1.2-2: Summary Results of Pre- and Post-Impact IHA Analysis at the Byfield USGS Gage

	Pre-impact period: WY 1946-89 (44 years)				*Post-impact period: WY 1990-2002 (13 years)*			
Watershed Area (sq mi)	21.3				21.3			
Mean Annual Flow (cfs)	36.98				36.96			
	Median		Coefficient of Dispersion		Deviation Factor		Significance Count	
	Pre	Post	Pre	Post	Median	Coefficient of Dispersion	Median	Coefficient of Dispersion
Parameter Group #1								
October (cfs)	6.4	9.7	1.85	1.88	0.53	0.01	0.37	0.98
November (cfs)	19.2	18.5	1.19	1.91	0.04	0.60	0.95	0.19
December (cfs)	33.5	36.4	1.10	0.87	0.08	0.21	0.87	0.65
January (cfs)	35.6	44.6	1.04	0.64	0.25	0.39	0.32	0.34
February (cfs)	43.8	38.5	0.80	0.87	0.12	0.09	0.64	0.85
March (cfs)	79.1	65.4	0.52	0.31	0.17	0.40	0.27	0.25
April (cfs)	74.0	71.1	0.65	0.78	0.04	0.20	0.86	0.64
May (cfs)	44.5	48.1	0.74	0.78	0.08	0.06	0.84	0.88
June (cfs)	20.0	12.0	0.94	1.75	0.40	0.86	0.26	0.10
July (cfs)	4.6	2.1	1.91	3.10	0.55	0.63	0.11	0.24
August (cfs)	4.2	0.8	1.56	10.73	0.80	5.87	0.08	0.00
September (cfs)	3.5	2.7	1.84	3.52	0.22	0.92	0.80	0.26
Parameter Group #2								
1-day minimum (cfs)	0.50	0.10	2.30	1.04	0.85	0.55	0.08	0.23
3-day minimum (cfs)	0.50	0.10	2.27	0.99	0.85	0.56	0.10	0.19
7-day minimum (cfs)	0.70	0.10	1.82	1.46	0.86	0.20	0.10	0.67
30-day minimum (cfs)	1.00	0.20	2.18	6.27	0.81	1.88	0.04	0.04
90-day minimum (cfs)	3.50	1.10	1.24	5.33	0.68	3.29	0.07	0.01
1-day maximum (cfs)	215.0	178.0	0.51	0.76	0.17	0.50	0.53	0.36
3-day maximum (cfs)	208.7	169.5	0.52	0.77	0.19	0.48	0.53	0.36
7-day maximum (cfs)	186.1	147.9	0.53	0.82	0.21	0.54	0.46	0.27
30-day maximum (cfs)	117.6	103.8	0.53	0.91	0.12	0.71	0.61	0.09
90-day maximum (cfs)	84.3	79.2	0.42	0.50	0.06	0.20	0.63	0.60
Base flow (cfs)	0.00	0.00	1.58	1.34	0.86	0.15	0.06	0.78
Parameter Group #3								
Date of minimum (Julian date)	263	247	0.08	0.12	0.09	0.36	0.17	0.65
Date of maximum (Julian date)	75	88	0.11	0.23	0.07	1.13	0.38	0.13
Parameter Group #4								
Low pulse count	3.0	3.5	1	0.29	0.17	0.71	0.15	0.04
Low pulse duration (days)	24.3	22.3	1.04	0.99	0.08	0.05	0.83	0.87
High pulse count	5	7	0.60	0.68	0.40	0.13	0.02	0.65
High pulse duration (days)	17.5	14	0.74	0.51	0.20	0.31	0.22	0.52
Parameter Group #5								

	Pre-impact period: WY 1946-89 (44 years)				*Post-impact period: WY 1990-2002 (13 years)*			
Watershed Area (sq mi)	21.3				21.3			
Mean Annual Flow (cfs)	36.98				36.96			
	Median		Coefficient of Dispersion		Deviation Factor		Significance Count	
Rise rate (cfs/day)	6	6	0.53	0.52	0.00	0.03	1.00	0.95
Fall rate (cfs/day)	-3	-3	-0.49	-0.57	0.00	0.14	0.95	0.71
Number of reversals	67	72	0.16	0.17	0.07	0.04	0.14	0.93

3.2 Evaluation of Unregulated/Natural Flow Regime

The USGS Streamstats Program was used to estimate an unregulated/natural flow regime in the Parker River (USGS 2000). The USGS has developed 13 equations that can be used to estimate various low flow streamflow statistics for locations on Massachusetts's streams. The equations were derived from regression analysis, which statistically relates the streamflow statistics for a group of USGS stations to physical characteristics (total length of stream, area of surficial stratified drift, mean basin slope, and hydrologic region) of the particular watershed. One of the equations can be used to estimate the 7-day, 10-year low flow (7Q10), a statistic used by the U.S. Environmental Protection Agency (EPA) and State agencies for permitting of pollutant (NPDES) discharges. Another equation estimates the August median flow, which is used by the U.S. Fish and Wildlife Service (USFWS) in New England as the minimum flow needed to maintain healthy aquatic ecosystems during low flow periods.

Output from the Streamstats program consists of the following statistics:

- 99%, 98%, 95%, 90%, 85%, 80%, 75%, 70%, 60% and 50% Annual Flow Exceedences,
- 7 day, 2 year low flow (7Q2) and 7 day, 10-year low flow (7Q10), and,
- August median flow (50% Flow Exceedence for the month of August)

The program also calculates prediction intervals at the 90% confidence level. The USGS noted limitations to using the Streamstats program. They recognize that the program may be used to calculate streamflow statistics at an existing USGS gage site to determine the difference in regulated and unregulated/natural flow conditions. They warn users not to assume that the differences between the two sets of estimates (regulated and unregulated/natural) are equivalent to the effects of human activities on streamflow at the station because there are errors associated with both sets of estimates.

For this study, the Streamstats program was used to estimate low flow statistics (for natural flow) at the Byfield USGS streamflow gage. Comparisons of low flow statistics for the estimated natural and actual flow conditions were then conducted as summarized in Table 3.2-1. Figure 3.2-1 illustrates the flow exceedance statistics computed for actual conditions (both the 1946-89 and 1990-2002 periods), as well as the maximum and minimum prediction interval computed by Streamstats.

In general, higher flows are predicted by Streamstats for several of the low flow statistics (99%, 98%, 95%, 90%, 85%, 80%, 75%, 7Q2, 7Q10 and August median flow), as compared to the actual measured flows at the Byfield USGS gage for both the WY 1946-89 and WY 1990-2002 periods. However, it is important to note that for the WY 1946-89 period, the 90% prediction interval computed by Streamstats encompasses the flow values computed from actual Byfield gage data. In contrast, for the period WY 1990-2002, the 99%, 98%, 95%, 90%, 85%, 80% flow exceedances, as well as the 7Q2, 7Q10 and August median flow statistics computed from actual Byfield gage data are well below the minimum prediction level computed by Streamstats. For higher frequency flows, such as the 75%, 60% and 50% exceedance values, the Streamstats program predicts comparable flow values relative to the actual measured flow at the Byfield USGS gage for both periods.

Table 3.2-1: Comparison of Annual Flow Statistics from the USGS Streamstats Program

Statistic	Flow Measured at Byfield USGS gage-WY 1946 to 1989 (cfs)	Flow Measured at Byfield USGS gage-WY 1990 to 2002 (cfs)	Streamstats Estimated Flow (cfs)	90% Prediction Interval for Streamstats	
				Minimum	Maximum
99-percent exceedance flow	0.28	0.06	0.96	0.28	3.05
98-percent exceedance flow	0.36	0.09	1.27	0.40	3.79
95-percent exceedance flow	0.81	0.17	1.96	0.72	5.13
90-percent exceedance flow	1.70	0.42	3.25	1.35	7.67
85-percent exceedance flow	2.80	0.93	4.46	1.96	9.94
80-percent exceedance flow	4.30	2.20	5.96	2.73	12.85
75-percent exceedance flow	6.20	4.70	7.80	3.72	16.13
70-percent exceedance flow	8.70	7.60	9.96	4.77	20.58
60-percent exceedance flow	15.0	15.0	16.05	8.80	29.11
50-percent exceedance flow	23.0	24.0	21.57	13.06	35.49
7-day, 2-year low flow	0.68	0.25	2.15	0.77	5.80
7-day, 10-year low flow	0.20	0.04	0.88	0.25	2.93
August median flow	3.30	0.77	4.82	2.10	10.83

3.3 Evaluation of Groundwater Levels

Groundwater levels were examined at two USGS monitoring wells to determine the degree of long-term and short-term aquifer depletion within the study area. The USGS maintains two ground water monitoring wells in close proximity to the study area. Georgetown well GCW 168 (#424322070592401) is located south of Route 133 along Winter Street at Murca Park in Georgetown. The well location is approximately 1.6 miles east of the GWD well field. Newbury well NIW 27 (#424520070562401) is located just east of Interstate 95 and north of Central Street in Newbury. This well location is approximately 0.7 miles north of the BWD’s Larkin Road wells, and 0.8 miles southeast of BWD’s Forest Street well. Both monitoring wells are located in sand and gravel aquifers, and have been in operation since 1965.

Figures 3.3-1 and 3.3-2 illustrate monthly groundwater levels at the Georgetown and Newbury USGS monitoring wells for the period 1965-2002, respectively. In addition, the 10th, 25th, 50th, 75th, and 90th percentile values for the entire period of record at each monitoring well are plotted. During the 1990-2002 period, very low groundwater levels were exhibited during the relatively dry summers of 1993, 1995, 1997, 1999, 2001, and 2002. However, during the ensuing spring groundwater levels were replenished to near normal levels (between the 75th and 90th percentiles, or greater, of all data points). Therefore, it appears there was no long-term aquifer depletion as a result of the preceding dry year.

The minimum annual groundwater levels experienced during the dry years of 1990-2002 were some of the lowest on record at the Georgetown monitoring well. The lowest recorded groundwater level at this well was on September 22, 1965 at 73.35 feet, mean sea level (msl). At the Newbury monitoring well, the lowest recorded groundwater level was on October 21, 1965 at 42.40 feet, msl. Overall, the groundwater levels at the Newbury monitoring well during the 1990-2002 period did not experience the same degree of drawdown seen at the Georgetown monitoring well. In addition, the lowest groundwater levels have typically occurred in August (total of 14 years out of 38 years) and September (total of 16 years out of 38 years) at the Georgetown well and during September (total of 12 years out of 38 years) and October (total of 15 years out of 38 years) at the Newbury well. Table 3.3-1 shows the date of the 15 lowest annual groundwater level readings at the Georgetown and Newbury wells (low levels occurring during the WY 1990-2002 period are shaded).

Table 3.3-1: Lowest Annual Groundwater Level Readings at the Georgetown and Newbury USGS Monitoring Wells

Georgetown		Newbury	
Date	**Well Level (ft, msl)**	**Date**	**Well Level (ft, msl)**
9/22/1965	73.35	10/21/1965	42.32
8/30/1995	73.39	11/5/1968	42.76
8/26/1974	73.57	9/27/1966	42.87
8/28/2002	73.57	11/27/2001	42.87
8/26/1966	73.6	10/31/1969	42.9
8/25/1993	73.61	11/25/1978	42.94
9/25/1997	73.62	10/30/1997	42.96
8/27/1999	73.65	9/20/1974	43.11
9/22/1980	73.75	9/25/1995	43.18
11/27/2001	73.81	9/20/1981	43.22
9/26/1978	73.82	10/25/1983	43.22
9/27/1968	73.86	9/15/1977	43.28
8/23/1987	73.9	10/10/1971	43.38
9/22/1983	73.91	10/10/1980	43.45
7/26/1976	73.94	10/20/1970	43.51

3.4 Evaluation of Precipitation Patterns

As shown in Figure 2.2-1, there are three long-term precipitation stations in close proximity to the Parker River watershed, which were used to determine the mean areal precipitation by an arithmetic averaging computation. Figure 3.4-1 illustrates the long-term annual (by Water Year) average precipitation totals for the Parker River watershed. As see in Table 3.4-1, under average conditions, precipitation totals are distributed fairly evenly on a monthly basis. However, due to natural hydrologic variability, extreme precipitation conditions occur on occasion.

Table 3.4-1 Monthly and Annual (WY) Precipitation Statistics (Period of Record WY 1946-2002)

	Average	**Standard Deviation**	**Maximum**	**Minimum**
January	3.9	2.2	11.9	0.4
February	3.5	1.6	8.3	0.3
March	4.1	2.3	12.6	0.8
April	3.9	1.9	11.4	0.5
May	3.7	2.0	11.3	0.9
June	3.3	2.3	11.9	0.6
July	3.3	1.5	6.7	0.7
August	3.3	1.9	9.9	1.1
September	3.7	2.2	8.7	0.6
October	3.8	2.4	14.2	0.3
November	4.7	2.3	12.4	0.6

	Average	Standard Deviation	Maximum	Minimum
December	4.3	2.1	9.8	1.1
Annual	45.3	7.4	66.3	30.2

Table 3.4-2 depicts the percent normal monthly and annual precipitation for the period WY 1990-2002. The table was developed in order to illustrate the timing, severity, and longevity of recent precipitation patterns. A percent normal value less than 100 corresponds to drier precipitation conditions, and vice versa. For instance, a percent normal value of 83 means that precipitation totals were 83% (or 17% less than the average) of the long term average (WY 1946-2002) for that particular time period. A percent normal of 100 would represent normal or average precipitation conditions. The gray shading in the table illustrates time periods that exhibited below normal precipitation.

Table 3.4-2: Percent Normal Monthly and Annual Precipitation for the Period WY 1990-2002

	WY 1990	WY 1991	WY 1992	WY 1993	WY 1994	WY 1995	WY 1996	WY 1997	WY 1998	WY 1999	WY 2000	WY 2001	WY 2002
October	173	254	79	67	108	15	164	376	38	140	100	90	41
November	89	53	90	114	81	83	180	56	134	40	49	112	23
December	33	97	85	119	140	164	77	140	86	37	38	104	75
January	93	86	88	53	124	118	158	78	153	172	88	59	82
February	108	60	65	151	54	113	91	57	195	102	90	72	72
March	40	91	88	205	168	50	85	127	108	105	80	306	102
April	153	140	71	151	72	55	154	144	77	12	146	28	102
May	164	63	59	29	143	75	87	92	175	91	83	48	152
June	30	78	146	53	30	53	58	52	314	20	158	170	139
July	73	96	125	66	58	85	205	55	45	118	190	59	44
August	181	231	134	38	148	38	37	99	81	43	72	103	61
September	43	190	88	139	205	79	204	56	91	237	104	70	113
Annual	97	118	92	102	112	79	126	112	124	92	97	104	83

On an annual basis, WY 1992 (92 percent normal), WY 1995 (79 percent normal), WY 1999 (92 percent normal), and WY 2002 (83 percent normal) were dry years relative to the overall period of record. During the 1990-2002 period, WY 1991 (118 percent normal), WY 1996 (126 percent normal), and WY 1998 (124 percent normal) were extremely wet years in terms of overall precipitation. During the typical low-flow months of June through September, the years of 1993, 1995 and 1997 show a sustained period of low precipitation. The period October 2001 to February 2002 was also unusually dry. The spring of 1999 was also unusually dry, when the months of April (12 percent normal) and June (20 percent normal) exhibited some of the lowest precipitation levels on record. It is also interesting to note that in 1996, the wettest July (205 percent normal) on record was followed by one of the driest Augusts (37 percent normal), only then to be followed by extremely wet months of September (204 percent normal) and October (376 percent normal).

Overall, precipitation patterns in the Parker River watershed experience some variability, predominantly due to the prevailing natural hydrologic conditions. Over the entire WY 1946-2002 period of record, both long-term and short-term droughts are not uncommon within the watershed. Both recent and historic episodes of drought have been documented. The most widely known sustained drought occurred during the 1963-66 period.

3.5 Analysis of Historic and Recent Low-Flow Conditions

The hydrologic characteristics (i.e. precipitation, streamflow) were compared between historic and recent dry periods to analyze the Parker River's response, in terms of streamflow, over time. The following is a general comparison, and it is recognized that several factors other than precipitation (i.e. groundwater elevations, air temperature, soil moisture) within a watershed can affect the timing and degree of low flow conditions.

WY 1957 and WY 1964 through 1966 represented both severe and prolonged dry periods within the Parker River watershed. The average annual flow for the WY 1946-2002 period is approximately 37 cfs, and the average total annual precipitation is 45.3 inches. By comparison, in WY 1966 the lowest annual average flow and the 6th lowest total annual precipitation were recorded within the watershed at 13.3 cfs and 34.4 inches, respectively. In WY 1957, the 8th lowest annual average flow (23.3 cfs) and the lowest total annual precipitation (30.2 inches) occurred. The lowest total precipitation (5.4 inches) for the period June-September occurred in WY 1957 as well. Table 3.5-1 shows the average annual flow, total annual precipitation, total precipitation for the June-September period, 7-day annual minimum flow, and the August median flow for each Water Year.

Table 3.5-1: Average Annual Flow, Total Annual Precipitation, Total Precipitation for the June-September Period, 7-day Annual Minimum Flow, and the August Median Flow for WY 1957, 1964-66

Water Year	Average Annual Flow (cfs)	Total Annual Precipitation (in)	Total Precipitation June-Sep (in)	7-day Annual Minimum Flow (cfs)	August Median Flow (cfs)
1957	23.3	30.2	5.4	0.10	0.4
1964	35.0	40.2	8.5	0.27	1.4
1965	16.1	33.2	10.1	0.34	0.5
1966	13.3	34.4	11.9	0.24	0.5

Several years during the 1990-2002 period also exhibited relatively dry conditions. Table 3.5-2 lists the average annual flow, total annual precipitation, total precipitation for the June-September period, 7-day annual minimum flow, and August median flow for dry years within this period. Overall, WY 1997 appeared to be a relatively wet year; however, most of the precipitation occurred in the month of October 1996 (14.2 inches). The remaining portion of the year was quite dry (36.7 inches). In addition, the June-September period of 1997 was one of the driest on record (8.9 inches).

Table 3.5-2: Average Annual Flow, Total Annual Precipitation, Total Precipitation for the June-September Period, 7-day Annual Minimum Flow, and August Median Flow for WY 1995, 1997, and 2002

Water Year	Average Annual Flow (cfs)	Total Annual Precipitation (in)	Total Precipitation June-Sep (in)	7-day Annual Minimum Flow (cfs)	August Median Flow (cfs)
1995	28.1	35.7	8.7	0.04	0.1
1997	59.7	50.9	8.9	0.09	0.2
2002	15.1	37.5	12.2	0.06	0.3

Even though 1957, 1965, and 1966 had lower precipitation levels relative to the dry years of the 1990-2002 period, the 7-day annual minimum flows were higher in 1957, 1965, and 1966. In addition, 1965 and 1966 were two dry years that occurred consecutively. However, the years preceding 1995 and 1997, and 2002 had above normal levels of precipitation. Total annual precipitation for 1994, 1996, and 2002 was 50.8 inches, 57.2 inches, and 47.0 inches, respectively. In 1957, the June-September precipitation totaled 5.4 inches, approximately 3.3 inches less that what occurred during the same period for the years

1995 and 1997. In spite of this, the 7-day annual minimum flow for 1957 was approximately equal to or greater than both what occurred during both 1995 and 1997. The same general trends are evident when comparing the 7-day annual minimum flows, as well as the August median flows for each year.

3.6 Streamflow Measurement Analysis

Streamflow measurements were completed along the Parker River on August 1 and October 24, 2002. Beginning at the headwaters of the watershed, measurements were completed at several locations, as depicted in Figure 3.6-1. Also shown in Figure 3.6-1 is the location of beaver dams along the mainstem Parker River. Beaver activity within the study area is described in more detail in Section 6. For the watershed area upstream of each measurement location, Table 3.6-1 illustrates the drainage area, stratified drift area, total stream length (includes tributaries), and mean watershed slope.

Table 3.6-1: Watershed Characteristics for Areas Upstream of Streamflow Measurement Locations

Measurement Location No.	Drainage Area (square miles)	Stratified Drift Area (square miles)	Total Stream Length (miles)	Mean Watershed Slope (%)
Site 1: Parker River at Glendale Road	1.12	0.19	2.81	2.18
Site 2: Parker River at Uptack Road	4.04	2.03	9.03	2.52
Site 3: Lufkins Brook-Tributary to Parker River	1.13	0.52	3.15	3.46
Site 4: Parker River Upstream of Rock Pond	6.19	3.13	15.02	2.61
Site 5: Parker River Downstream of Rock Pond	6.87	3.56	15.39	2.53
Site 6: Parker River Downstream of Pentucket Pond	7.55	3.84	17.57	2.32
Site 7: Penn Brook-Tributary to Parker River	4.00	1.65	12.08	2.66
Site 8: Parker River at Thurlow Street	13.15	6.79	37.52	2.25
Site 9: Parker River near Forest Street	20.87	9.65	58.11	2.11
Site 10: Parker River at Byfield USGS Gage	21.3	9.83	59.29	2.11

The goal of this analysis was to identify potential losses or gains within the system, as the river progresses downstream to the Byfield USGS gage. Flow measurements followed standard USGS stream gaging procedures. These flow measurements were computed using the formula Q=VA where;

Q= flow (cfs),
V= velocity (ft/sec), and
A= area (ft).

Prior to flow metering a tape measure was placed across the river channel. Starting on the right bank looking upstream, a Marsh-McBirney Flow-Mate 2000 velocity meter was placed in the water, and pertinent data were recorded at 0.5-1.0 foot increments (cells) across the stream channel. The data collected for each cell consisted of mean column velocity (measured to the nearest 0.01 ft/sec), depth (measured to the nearest 0.05 foot) and width (measured to the nearest 0.1 foot). These data were used to compute the flow in each cell using the formula above. The flow within each cell was then summed to yield the total river flow.

Figure 3.6-2 shows a schematic of the river system, along with the streamflow measurement locations and results for both the August 1 and October 24, 2002 site visits. Also, Figure 3.6-3 illustrates the river mile location of the measurement sites versus the corresponding measured flow, in cubic feet per second per square mile of drainage area (cfsm), for both site visits. The units of cfsm are attained by dividing a given flow (cfs) by the corresponding drainage area (square miles) at the measurement site. In an "ideal" watershed, the streamflow in units of cfsm should remain relatively constant throughout a watershed.

During both site visits (Figure 3.6-3), streamflow, in cfsm, began to steadily decline after the Uptack Road measurement location, in the vicinity of the GWD well complex. Streamflow began to increase between the Pentucket Pond and Thurlow Street measurement locations, partly due to the contribution of the Penn Brook tributary. This increase was more apparent at the October 24 site visit, when Penn Brook contributed 0.26 cfsm, relative to the 0.04 cfsm that was exiting from Pentucket Pond. Streamflow declined between the Thurlow Street and Byfield USGS gage measurement locations during both site visits. During the second site visit, a measurement location was added upstream of Byfield's Forest Street water withdrawal point. The stream reach encompassed by the well (between the new measurement location and the Byfield USGS gage) showed a slight loss in flow, relative to the reach immediately upstream.

With regard to the river segment between Uptack Road and Pentucket Pond, there appears to be some loss within the system at these locations. It is likely that the low flow conditions at the time of the measurements, coupled with evaporative effects from these relatively large ponds (total surface area of 135 acres) are partly attributable to this condition. At Pentucket Pond Dam, the water level control structure consists of two stop log bays, while Rock Pond has a natural outlet. The stop logs at Pentucket Pond are likely removed only during times of flooding. In most instances, the stop logs help maintain Pentucket Pond at a relatively constant elevation; however, during times of low inflow to Rock and Pentucket Ponds, surface evaporation and groundwater recharge could exceed inflow to the Ponds causing the water elevation to fall below the stop log crest elevation. This situation allows only a small amount of leakage to pass downstream from Pentucket Pond Dam.

During both streamflow measurement site visits, the water level at Pentucket Pond Dam was below the stop log crest elevation. However, both Pentucket and Rock Ponds have been in the watershed for a long period[5], therefore, it is unlikely that this situation has contributed to the recent low flow conditions. This situation also affects the Parker River hydrology in another manner. When precipitation does fall after a dry period, most of the resulting runoff is stored in the Ponds up to the stop log crest elevation. Only after sufficient precipitation has fallen, does the water elevation increase to allow flow into the Parker River below Pentucket Pond Dam.

Figure 3.6-4 illustrates the total daily precipitation, monthly groundwater levels (Georgetown USGS well), and average daily streamflow for the period June 1 to December 31, 2002. During the previous 31 days before the August 1st site visit the watershed received a relatively low amount of precipitation (1.03 inches), also streamflow decreased from 22 cfs to 0.95 cfs in this time. As evidenced by the low precipitation totals, decreasing groundwater levels, and base flow conditions, it appears that streamflow during the August 1st field visit was being predominantly supplied by discharge from groundwater and wetland sources. This process seems to have continued throughout most of the remaining summer period.

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[5] Pentucket Pond Dam was rebuild in the late 1990's.

From September 15th to October 11th, total precipitation was at near normal levels (3.16 inches), which appeared to help recharge groundwater and wetland levels somewhat. However, streamflow within the watershed lagged and did not respond appreciably to this precipitation input. Streamflow on September 15th was 0.07 cfs, and only managed to increase to 0.95 cfs on October 11th. During the ensuing two weeks, total precipitation was above normal levels (4.07 inches), and streamflow responded by increasing to 9.6 cfs on October 28th. During the final two months of the year, total precipitation was quite high (9.58 inches) resulting in moderate recovery of streamflow and groundwater levels.

During the October 24th site visit, the streamflow upstream of Pentucket Pond was very low. The outflow from Pentucket Pond was 0.30 cfs, while the total flow measured at the Byfield USGS gage was 2.20 cfs. This is contrasted with the August 1st site visit, when outflow from Pentucket Pond was 0.25 cfs and the total flow at the Byfield USGS gage was 0.94 cfs. Penn Brook provided the majority of total flow measured at the Byfield USGS gage during the October 24th field visit, even though this tributary only has a drainage area of 4.0 square miles compared to the 21.3 square mile drainage area at the gage. Other than the Penn Brook watershed, it seems likely that the groundwater levels, numerous wetland complexes, and ponds throughout the remaining watershed were in a state of recharge in the weeks prior to the October 24th field visit. Another factor that may have contributed to the higher flow in Penn Brook, is it being relatively free of water supply withdrawals.

Also, as seen on Figure 3.6-2 the Georgetown well field is along this stream reach between measurement sites 2 (Uptack Road) and 4 (Upstream of Rock Pond), in addition three beaver dams are also situated near the well complex. Streamflow began to decrease steadily beginning at measurement site 2. This entire area is a large wetland complex without a definable river channel; therefore this river segment could not be delineated any further to isolate the potential impacts of the beaver dam or well field. However, other stream reaches also contained several beaver dams as well, including the stream reach between measurement sites 1 and 2, where streamflow actually increased.

Figure 3.2-1: Comparison of Estimated Natural Flow Regime versus Actual Flows Measured at the Byfield USGS Gage

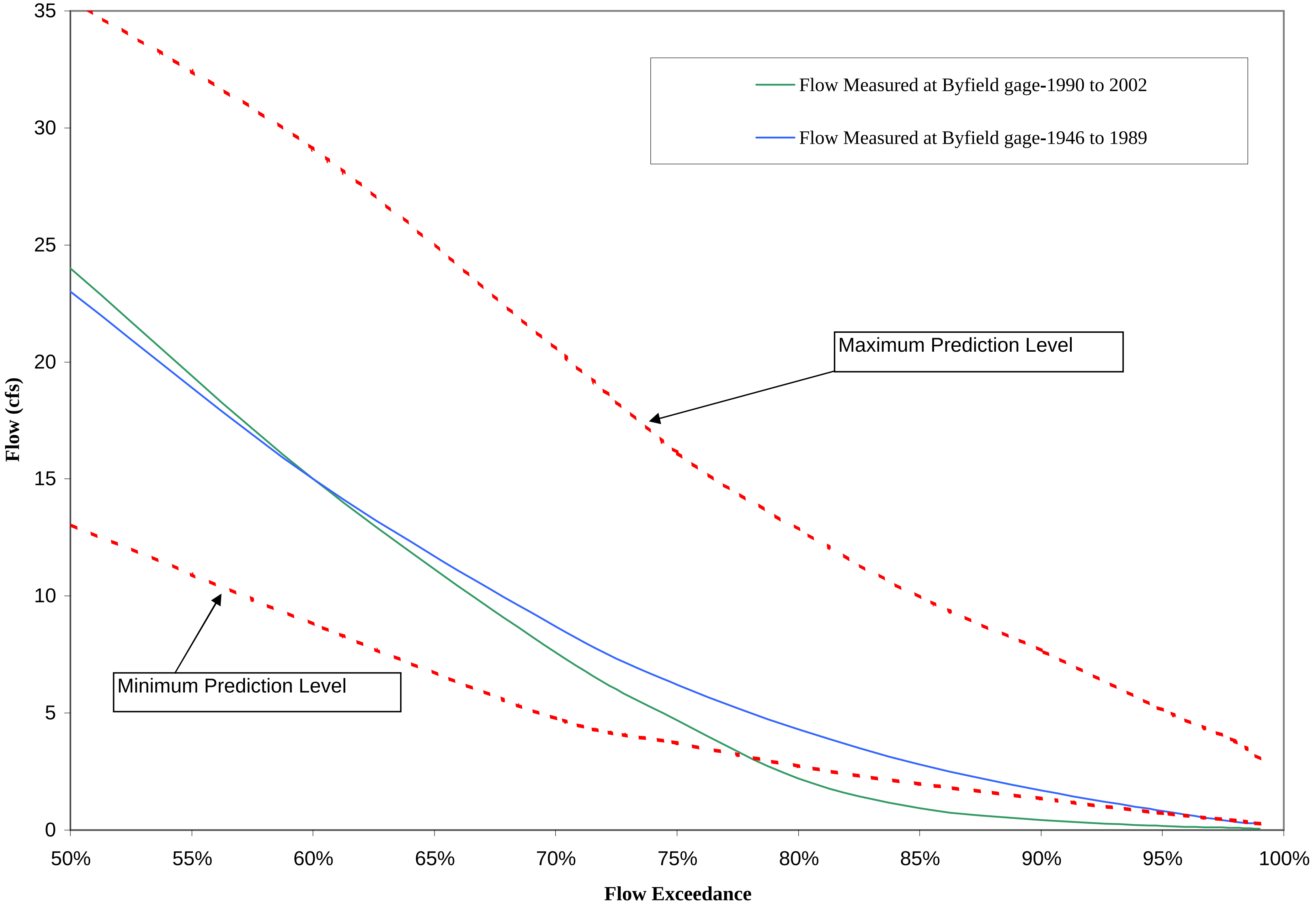


Figure 3.3-1: Monthly Groundwater Levels for the Period 1965-2002 at USGS Monitoring Well Located in Georgetown

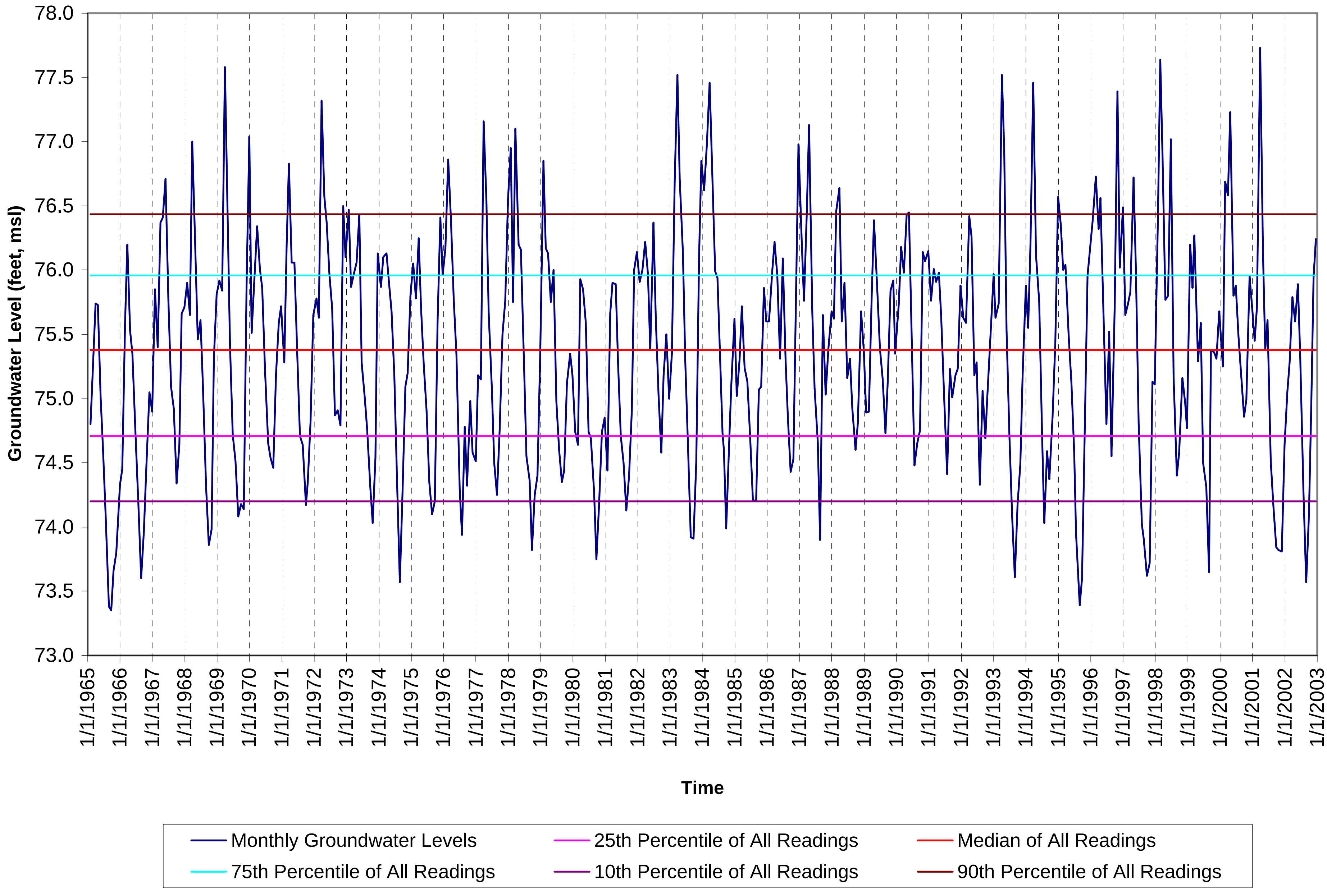


Figure 3.3-2: Monthly Groundwater Levels for the Period 1965-2002 at USGS Monitoring Well Located in Newbury

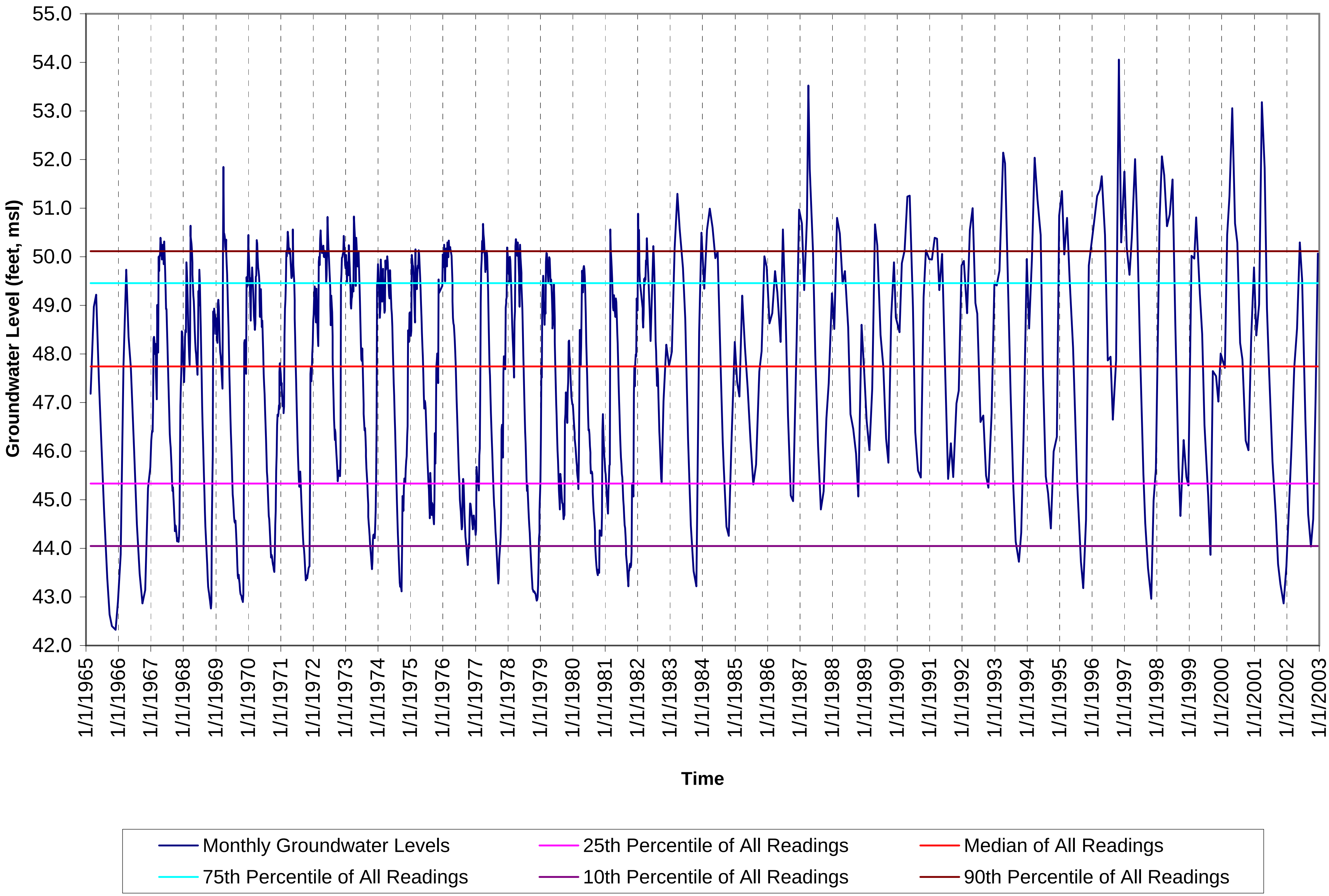


Figure 3.4-1: Annual Average Precipitation for WY 1946-2002

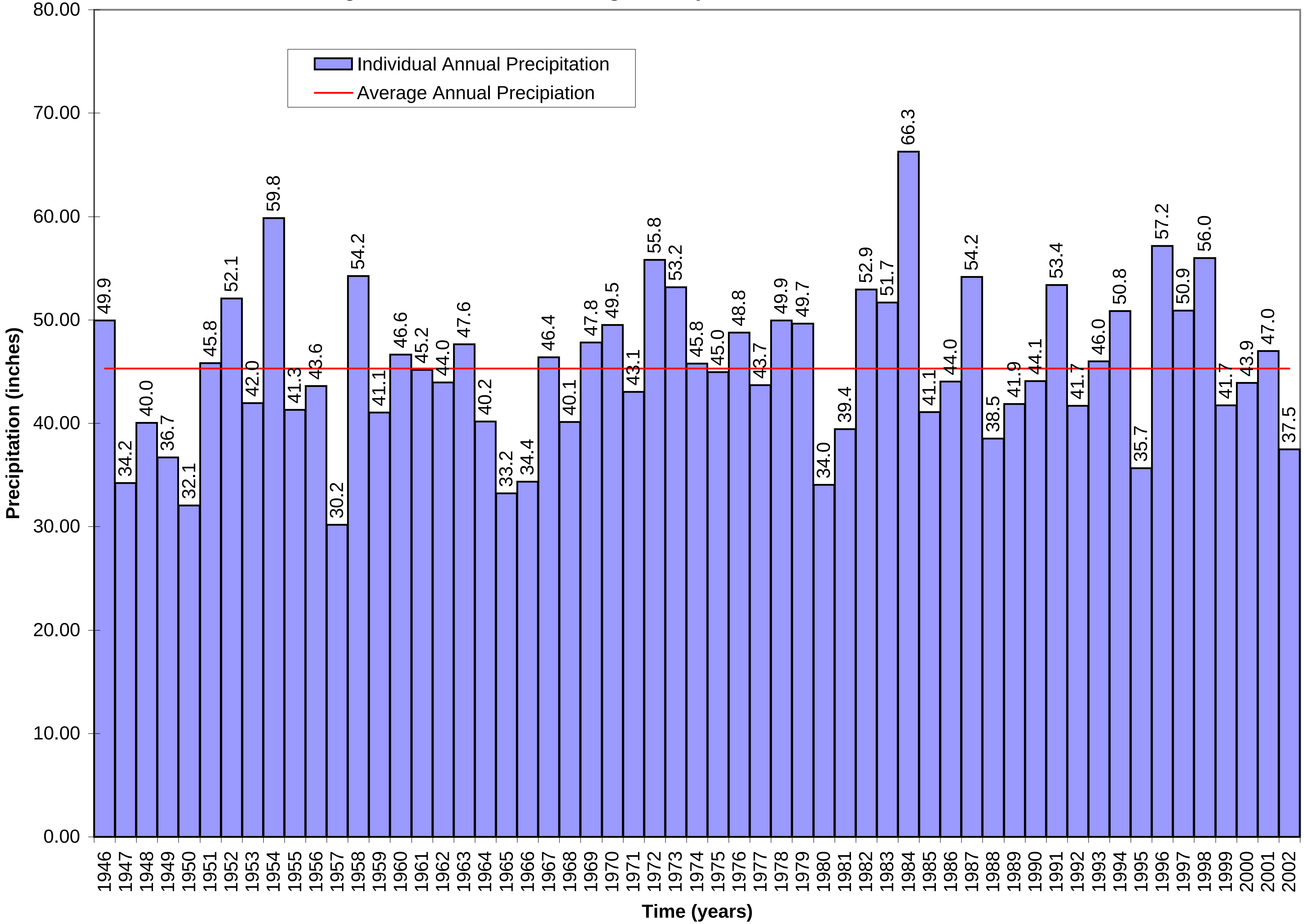


Figure 3.6-1: Streamflow Measurement and Beaver Dam Locations

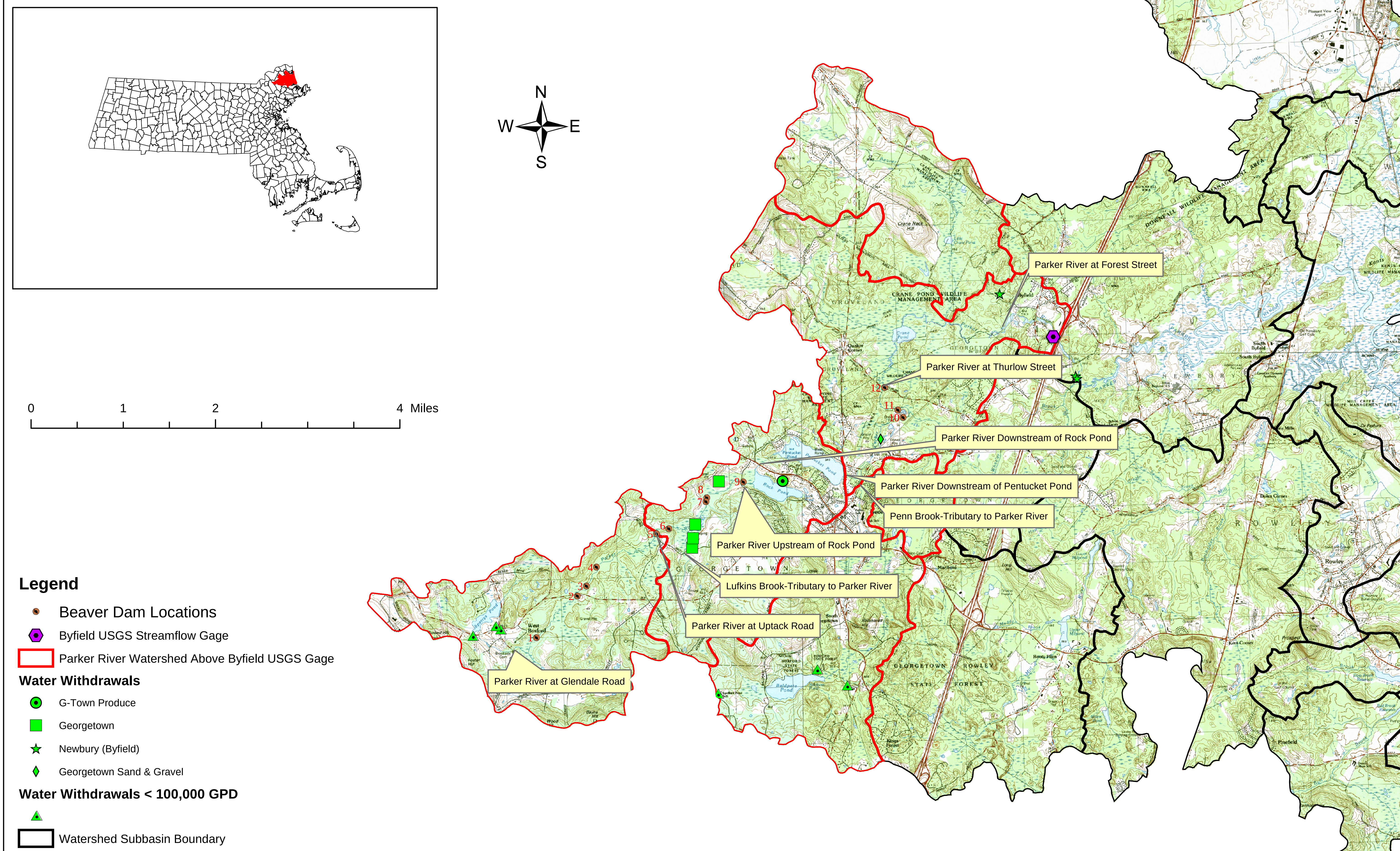


Figure 3.6-2: Schematic Showing Location and Results of Streamflow Measurement Study-August 1 and October 24, 2002

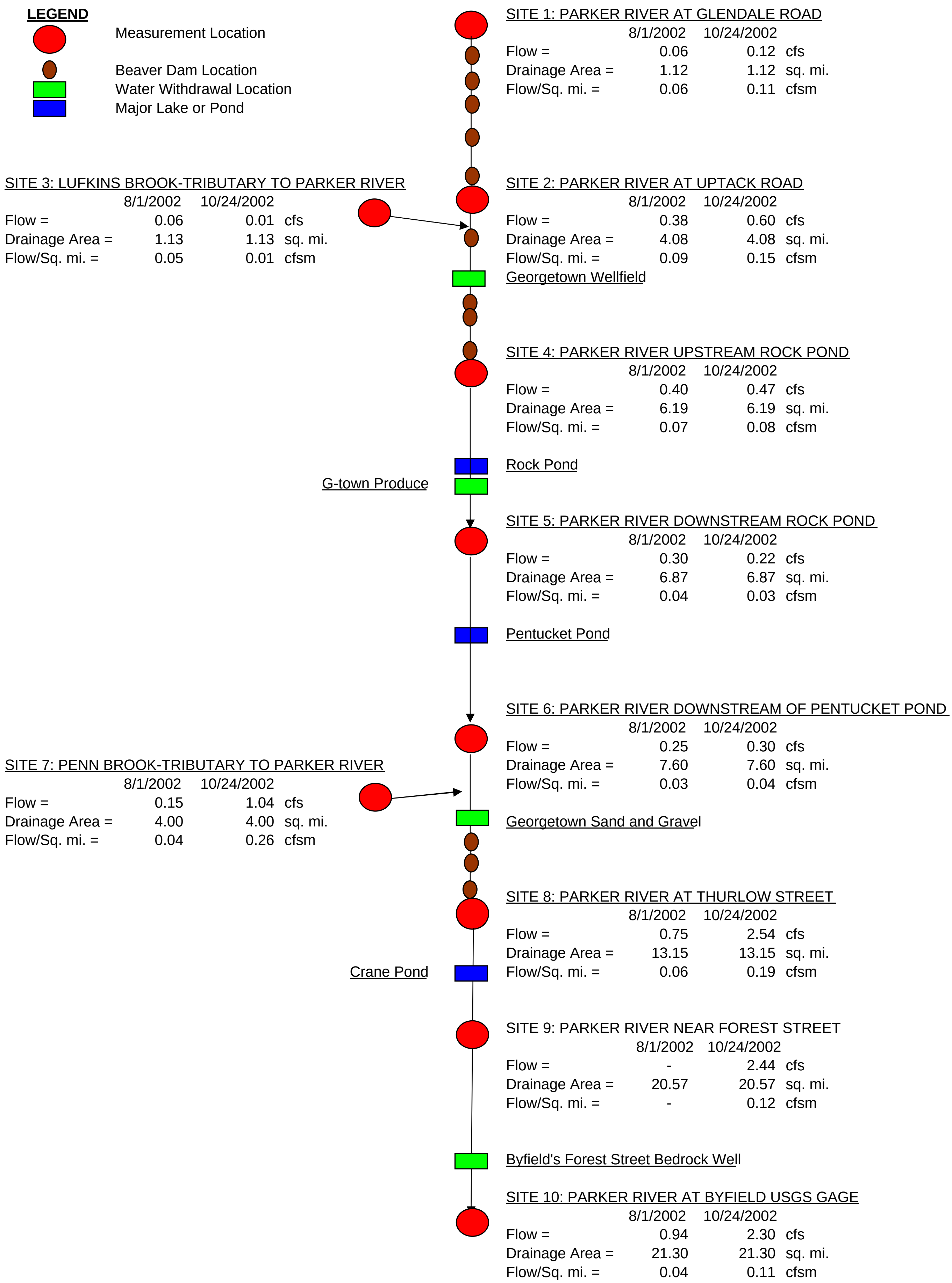


Figure 3.6-3: Streamflow Measurement Results

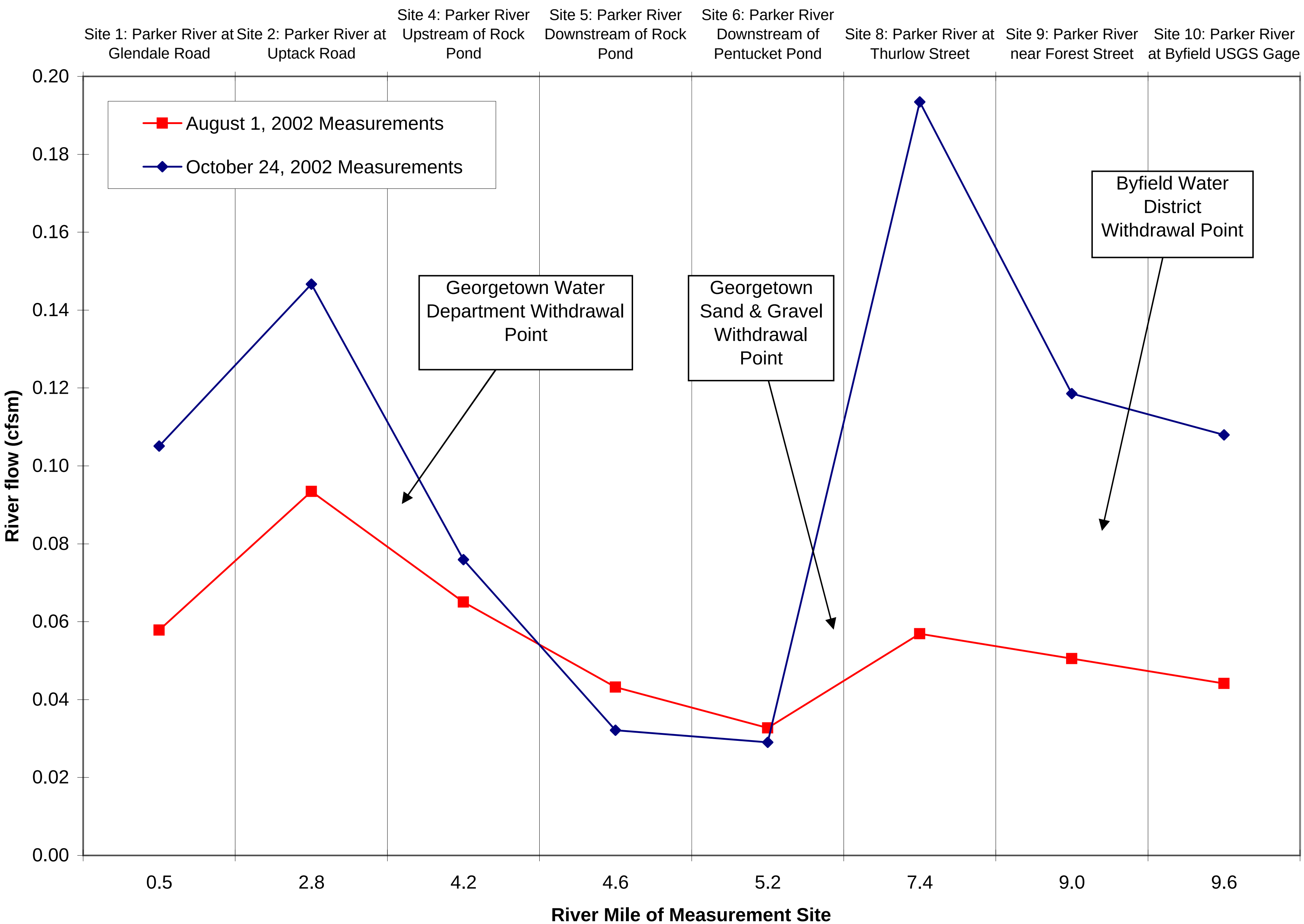
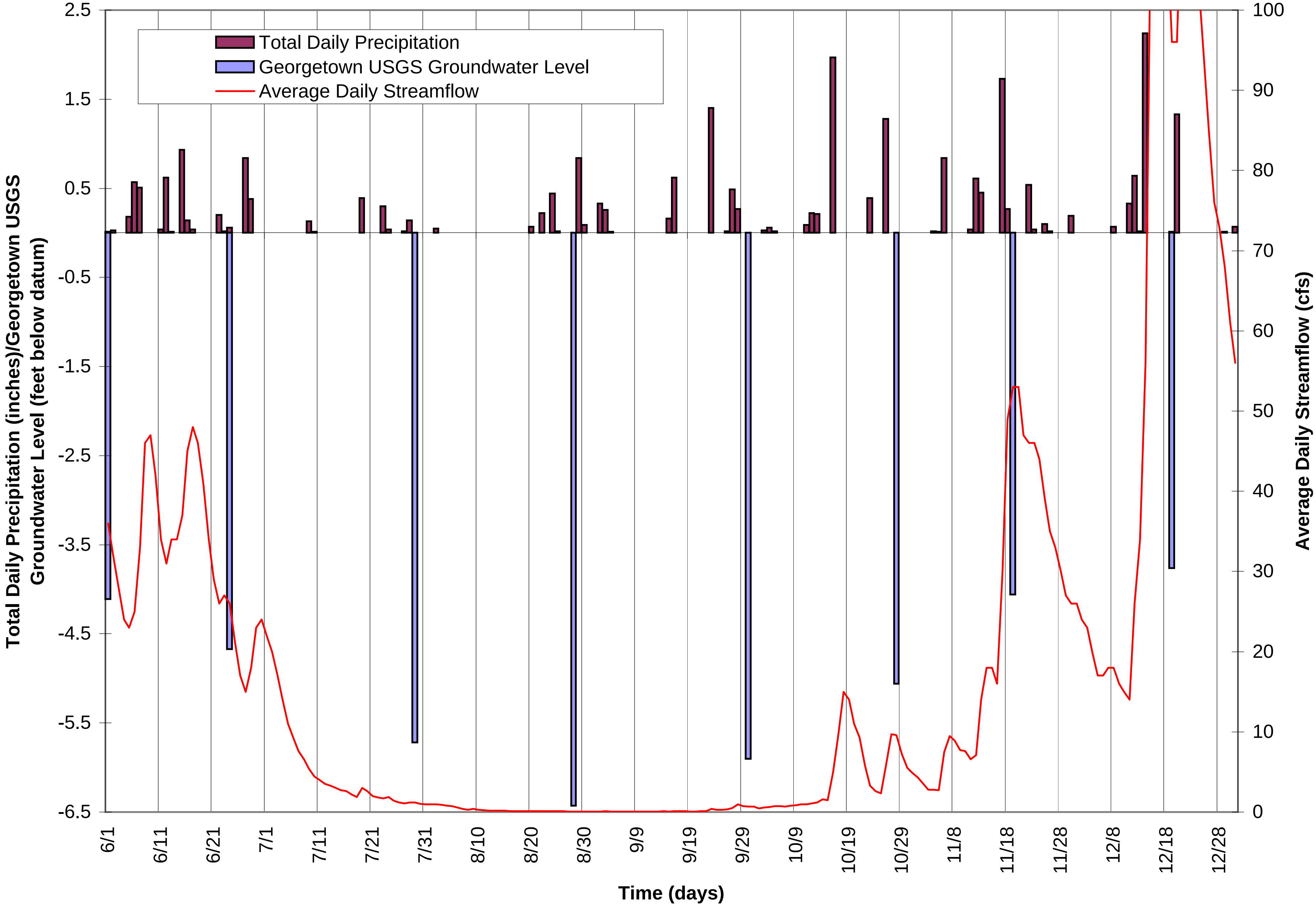


Figure 3.6-4: Total Daily Precipitation, Monthly Groundwater Levels, and Streamflow Hydrograph for Period June 1 to December 31, 2002



4 Evaluation of Water Management Act Withdrawals and Discharges

The Massachusetts Water Management Act (WMA) became effective in March 1986. The purpose of the Act is to ensure adequate volume and quantity of water for all citizens of the Commonwealth, as well as to protect the natural environment of the water in the Commonwealth. Implementation of the WMA has taken place in two phases: registration and permitting of water withdrawals. The deadline for filing registration statements under the WMA was January 4, 1988. The purpose of the registration was to grant continued water rights to existing water withdrawals and to provide the MDEP with information needed to begin the process of comprehensive water management. Registrations were based on the applicant's average water use for the period 1981-85. The permitting phase of the program went into effect over several years.

Anyone with a water withdrawal in Massachusetts that averages over 100,000 gallons per day (GPD) and is not registered is required to obtain a permit. Persons who have registered and now exceed their registered withdrawal by 100,000 GPD or propose an increase in the amount they withdraw are also required to obtain a permit. These conditions apply to any entity withdrawing water such as public water suppliers and industrial, commercial, golf courses and agricultural users. Those who obtain (purchase or transfer) their water from another water system do not require a permit.

There are several water withdrawal locations within the Parker River watershed, many users withdraw less than 100,000 GPD, and thus no permit is needed. The objective of this study was to focus on low flow in the Parker River above the Byfield USGS streamflow gage. Therefore, registered/permitted withdrawals located upstream of the gage are examined in detail, as shown in Table 4.0-1. Below-threshold water users (<100,000 GPD) are described in less detail in subsequent portions of this section. Figure 4.0-1 depicts both registered and non-registered public water withdrawals, as well as registered private water withdrawals.

Table 4.0-1: Registered and Permitted Water Withdrawals in the Parker River Watershed Above the USGS Gage in Byfield, MA (>100,000 GPD or 0.1 MGD)

Name	Registration/Permit No.	Registered Amount	Registered/Permitted No. of Withdrawal Points (SW- surface water, GW- groundwater)	Authorized Average Daily Withdrawal (2001) (MGD)	Percent Distribution of Authorized Daily Withdrawals above the Byfield gage (current)
Byfield Water District	3-16-205.1	0.17	2 GW	0.17	10.8%
Georgetown Water Department	3-16-105.01	0.43	4 GW	0.73	46.5%
Georgetown Sand and Gravel Co.	9P-3-16-105.02	0.57	1 SW	0.57	36.3%
G-town Produce	3-16-105.02	0.10	1 SW	0.10	6.4%
			Total	1.57 MGD	

MDEP Wilmington and Boston offices were visited to obtain copies of the reports listed below, which were used to evaluate water withdrawals in the Parker River watershed:

- The Registration Statement for each water withdrawal,
- The water withdrawal permit [Massachusetts General Law (MGL) c 21G],
- Public Water Supply Annual Statistical Reports (PWSASR) were obtained from water suppliers for the period 1990 to 2001.
- Registered & Permitted Withdrawals Annual Reports were obtained for industrial, agricultural and golf course withdrawals for the period 1990 to 2001. It should also be noted that the public water supply reports and industrial reports contain the same basic information, although the public water supply reports contain information on peak water usage and population served.

4.1 Description of Georgetown Water System

Public Water Supply No.: 3105000
Registration No.: 3-16-105.01

The Georgetown Water Department (GWD) registered for water withdrawals in 1991 from three groundwater wells having an allowable average withdrawal volume per day of 0.43 MGD (156.10 MGY). The three wells and the year of their original installation are Marshall Well (1964) and Tubular Wellfield (1934), both located on West Street, and Commissioners Well (1982) located on Bailey Lane.

On August 14, 1996 MDEP reissued a water withdrawal permit to GWD. The new permit identifies an additional water withdrawal location: Duffy's Landing Well on West Street. The permit authorizes the withdrawal of water, on average over the calendar year, at the rates shown in Table 4.1-1. The volumes reflected in Table 4.1-1 include the 0.43 MGD previously registered to the GWD through the WMA Program. On May 31, 2002, the GWD water withdrawal permit was renewed as part of the WMA 5-year permit review requirement.

Table 4.1-1: Georgetown Water Department, Authorized Withdrawal Volumes

Period	Permitted Daily Rate (MGD)	Previous Registered Daily Rate (MGD)	Total Daily Rate (MGD)	Total Annual (MGY)
8/14/1996-2/28/2000	0.27	0.43	0.70	254.65
03/02/2000-02/28/2005	0.30	0.43	0.73	265.60
03/01/2005-2/28/2010	0.32	0.43	0.75	272.90
03/01/2010-2/28/2015	0.32	0.43	0.75	272.90

Withdrawals from individual water sources are not to exceed the approved daily volumes listed in Table 4.1-2.

Table 4.1-2: Georgetown Water Department, Water Supply Source, Location, and Maximum Daily Withdrawal Rates

Source	Location	Maximum Daily Withdrawal Rates (MGD)
Tubular Wellfield	West Street	0.29
Marshall G.P. Well	West Street	1.00
Commissioner's Well	Bailey Lane	0.58
Duffy's Landing Well	West Street	1.51

4.1.1 Annual and Monthly Withdrawal Volumes

Shown in Table 4.1.1-1 is the annual total withdrawal volume (MGY), average daily withdrawal (MGD), peak day withdrawal (MGD), and the ratio of peak day/average daily withdrawal and percent of water sold to other systems for the period 1990-2001. The annual withdrawal volume during this period has risen consistently, ranging from 0.49 MGD in 1990 to 0.72 MGD in 2001. For each year, GWD has stayed within their permitted limits for average daily withdrawal rates. The amount of water sold to other systems has been consistently very low. With the exception of 2000 when water was sold to Rowley Water Department (whose service territory is below the Byfield USGS gage), all the water sold in previous years was to the Byfield Water District (BWD).

Table 4.1.1-1: Georgetown Water Department: Annual Withdrawal Summary

Year	Annual Withdrawal (MGY)	Average Daily Withdrawal (MGD)	Peak Day Withdrawal (MGD)	Ratio of Peak Day/Average Daily Withdrawal	Percent of water sold to other systems (%)
1990	177	0.49	1.21	2.49	0.4
1991	193	0.55	1.20	2.19	0.0
1992	190	0.52	0.94	1.81	3.6
1993	223	0.61	1.48	2.42	1.0
1994	231	0.63	1.53	2.42	0.4
1995	249	0.68	1.72	2.52	0.2
1996	229	0.63	1.30	2.06	0.5
1997	248	0.68	1.53	2.25	0.1
1998	259	0.71	1.63	2.29	0.1
1999	255	0.70	2.06	2.96	0.0
2000	256	0.70	1.89	2.71	0.2
2001	263	0.72	1.60	2.22	0.0

Over these 12 years, the peak day withdrawal has occurred mainly in the summer months as follows: May (1), June (4), July (6), and October (1). The average difference between the average daily withdrawal and peak day withdrawal over the last 12 years is approximately 0.87 MGD. The average ratio of peak day withdrawal relative to average daily withdrawal is 2.36.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.1.1-1 is a bar graph depicting the monthly water withdrawals by GWD. The monthly water usage varies significantly ranging from a low of 13.3 MG in February to 29.0 MG in July. Water demands are highest in the summer and lowest in the winter.

4.1.2 Population Served

The Public Water Supply Annual Statistical Reports (PWSASRs) show the summer population ranging from 6,400 in 1990 to 7,000 in 1995. These population estimates closely approximate the federal census year round population for the town of Georgetown. However, after 1995, the population served is reported by GWD as the number of service connections. Due to the change in methods used to estimate the population of Georgetown, the population data reported on the PWSASRs after 1995 were deemed unreliable. MDEM reports that GWD services approximately 98% of Georgetown. Therefore, federal census data were relied upon to investigate the trends associated with population growth and water use. This information was supplemented with population data provided by the Georgetown town clerk which were only available for the 1999-2001 period.

Shown in Figure 4.1.2-1 is the actual population obtained from federal census data as well as the Georgetown town clerk, plotted with the average daily water consumption for each year from 1990-2001. Daily water use in Georgetown has increased steadily from 0.49 MGD in 1990 to 0.72 MGD in 2001, an increase of 48%. The population of Georgetown grew 16% from 1990 (6,384) to 2001 (7,421). It is likely that outdoor water use and residential irrigation is responsible for this disproportionate water use increase relative to population growth.

Dividing the average number of gallons used per day (annual residential use) by the population served will yield the gallons per capita day (gpcd). The state's water conservation goal is to limit residential use to 80 gpcd. Using 2001 data, GWD had an estimated 79 gpcd of residential water consumption. Due to inconsistencies in the population reporting method, no attempt was made to compute historic gpcd values for comparison purposes.

Georgetown has above ground water storage tanks totaling 1.5 MG in capacity. The town of Georgetown does not operate a wastewater treatment facility.

4.1.3 Water Conservation Measures/Unaccounted for Water

According to the most recent Water Withdrawal Permit, GWD does have a Water Conservation Plan and Plan of Action that includes an ongoing program to repair or replace all meters over 15 years old and a leak detection and repair program. All public buildings served by GWD are fitted with water saving devices and an education program to inform customers of the benefits of water conservation are also part of the plan. GWD also institutes an increasing block-rate fee structure. As of May 3, 2002, GWD had implemented a mandatory restriction on outside (odd/even watering during specific times) water use in response to drought conditions. The level of enforcement and compliance to this restriction is not known.

Water providers must also report unaccounted for water (leaks, fire hydrant flushing, pipeline flushing, etc). In 2001, unaccounted for water constituted 8% of the total water supplied by GWD. This value is below the state's water conservation goal of less than 10%. The MDEP requires that water suppliers having 15% or greater unaccounted for water indicate the possible reasons.

4.1.4 Inflow/Outflow Analysis

An inflow/outflow analysis was performed for the service area of GWD. All the water withdrawn from GWD's wells is taken from locations above the Byfield USGS gage. Most of this water is distributed for consumption in Georgetown above the Byfield USGS gage. A small portion of water was exported over the past twelve years, usually to the BWD. The GWD service area does not contain sewer lines, thus residents and businesses dispose of wastewater via septic systems. We have assumed that 75% of water use is returned to the drainage area via septic systems (Gomez and Sullivan 2002), with the balance being lost to evapotranspiration and consumptive use.

Figure 4.1.4-1 shows the estimated amount of water returned and lost from the area above the Byfield USGS gage, based on all water withdrawals and distribution by GWD. GWD has not exported any water since January, 1998. As the figure depicts, most of the water withdrawn is discharged above the gage, excluding the evaporative losses. Water that was eventually discharged below the gage was sold to Byfield, which then distributed a portion of the water to customers located downstream of the gage. Our analysis of BWD's water distribution system estimates that approximately 21% of the water distributed by BWD is conveyed above the USGS gage; with the balance conveyed to customers below the gage.

4.2 Description of Byfield Water System (Town of Newbury)

Public Water Supply No.: 3205001
Registration No.: 3-16-205.1

The Byfield Water District (BWD), located in the Town of Newbury, initially registered for water withdrawals in 1991 from a gravel packed well located at 35 Larkin Road along the Parker River in Newbury. The well is located below the Byfield USGS gage and was originally installed in 1970. The allowable average withdrawal volume is 0.168 MGD (61.44 MGY). Although the Registration Statement for Water Withdrawals filed with the MDEP only specifies the use of one groundwater withdrawal point, BWD's PWSASRs indicate that water is withdrawn from two wells located on Larkin Road (wells identified as 3205001-02G and 3205001-03G).

On September 1, 1998, MDEP reissued a water withdrawal permit to BWD, allowing the use of a new withdrawal point-the Forest Street Bedrock Well in Byfield. This well was intended to replace the existing Larkin Road Bedrock Well which was found to be "under the influence of surface water," (i.e., the well derives recharge from the river under certain pumping thresholds) according to the new permit. The use of this new well is significant to this study because it draws groundwater from an area located upstream of the USGS stream gaging station in Byfield; the previous withdrawal points were located downstream of the gage. It should be noted that the Larkin Road Well has been used on a limited basis since September, 1998.

The new permit did not grant an increase in total water withdrawals (the existing average daily withdrawal is 0.17 MGD). MDEP does allow BWD to withdraw up to 100,000 gallons of water per day in excess of the registered volume, up to a limit of 0.27 MGD. The maximum daily withdrawal rate from the Forest Street Well is 0.36 MGD. In 2002, the BWD water withdrawal permit was renewed as part of the WMA 5-year permit review requirement.

4.2.1 Annual and Monthly Withdrawal Volumes

Shown in Table 4.2.1-1 is the annual total withdrawal volume (MGY), average daily withdrawal (MGD), peak day withdrawal (MGD), and the ratio of peak day/average daily withdrawal for the period 1990-2001. The annual withdrawal volume ranged from 0.16 MGD in 1994 to 0.22 MGD in 1999. Overall, the average daily use is fairly consistent; there is a difference of approximately 0.05 MGD between 1990 and 2001. Byfield occasionally purchases water from Georgetown Water Department; however, this amount is usually below two percent of Byfield's total water consumption for that given year.

Table 4.2.1-1: Byfield Water District: Annual Withdrawal Summary From All Withdrawal Points (shading indicates when some withdrawals switched to point above the gage)

Year	Annual Withdrawal (MGY)	Average Daily Withdrawal (MGD)	Peak Day Withdrawal (MGD)	Ratio of Peak Day/Average Daily Withdrawal
1990	62.6	0.17	0.47	2.71
1991	65.4	0.18	0.36	2.01
1992	62.6	0.18	0.39	2.10
1993	57.7	0.16	0.60	3.82
1994	57.0	0.16	0.36	2.27
1995	70.0	0.19	0.49	2.52
1996	62.4	0.17	0.35	2.05
1997	73.0	0.20	0.45	2.24

Year	Annual Withdrawal (MGY)	Average Daily Withdrawal (MGD)	Peak Day Withdrawal (MGD)	Ratio of Peak Day/Average Daily Withdrawal
1998	77.4	0.21	0.38	1.81
1999	79.3	0.22	0.52	2.39
2000	68.8	0.19	0.29	1.55
2001	72.3	0.20	0.37	1.88

From 1990-2001, the peak day withdrawal has occurred mainly in the summer months as follows: April (1), May (1), June (5), July (4), and November (1). The average difference between the average daily withdrawal and peak day withdrawal over the last 12 years is approximately 0.23 MGD. The average ratio of peak day withdrawal relative to average daily withdrawal is 2.28.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.2.1-1 is a bar graph depicting the monthly water withdrawals by BWD. The monthly water usage varies significantly ranging from a low of 4.35 MG in February to 7.42 MG in July. Similar to Georgetown, water demands in Byfield are highest in the summer and lowest in the winter. In addition, since this study has an emphasize on low water flows as measured at the Byfield USGS gage, seasonal demand was evaluated from the Forest Street Well, which is above the gage, after the well went into use in September, 1998. Figure 4.2.1-2 shows the monthly average withdrawals from the Forest Street Well for the period 1999-2001. The timing of peak monthly withdrawals from the Forest Street Well is different than the long term monthly average shown in Figure 4.2.1-1 because BWD pumps water from the Larkin Street Well during the spring and summer months to meet increased demand (see Figure 4.2.1-3).

4.2.2 Population Served

In the revised Water Withdrawal Permit issued to BWD in 1998, MDEP infers from their population projections that BWD's water demand will be 0.18 MGD in 2000, increasing to 0.20 MGD in 2015.

BWD's service area includes most of the Village of Byfield. BWD does not serve residents that live in the sections of the Town of Newbury referred to as Old Town, nor do they serve residents of Plum Island (half of which is part of Newbury). The PWSASR shows the summer and winter population served for each year from 1990-2001. With the exception of 2001, the population numbers were estimates; the most accurate number of population served was reported in 2001 (P. Colby, BWD superintendent, personal communication). Due to the change in reporting methods, the population data reported on the PWSASRs prior to 2001 were deemed unreliable. The MDEM calculated BWD's service population for 1990 as 1,800 (S. Asen, MDEM, personal communication). The 1990 and 2001 service population data were used to assess water use and population trends.

Shown in Figure 4.2.2-1 is BWD's service population for 1990 and 2001, plotted with the average daily water consumption for each year from 1990-2001. Daily water use has increased from 0.17 MGD in 1990 to 0.20 MGD in 2001, an increase of 14%. BWD's service population grew 12% from 1990 (1,800) to 2000 (2,015).

The 2001 PWSASR reported the population served to be 2,015. Based on this population, the daily per capita water usage was calculated to be 72 gpcd, which is below the state's water conservation goal. Using MDEM's 1990 service population calculation BWD's 1990 daily per capita water usage was calculated to be 75 gpcd. Due to inconsistencies in the population reporting method, no attempt was made to compute annual gpcd values for intervening years during the 1990-2001 period.

Byfield has above ground water storage tanks totaling approximately 0.5 MG in capacity. The BWD service area does not contain sewer lines, thus wastewater is disposed via septic systems.

4.2.3 Water Conservation Measures/Unaccounted for Water

BWD has a formal water conservation plan in place. Individual service meters are inspected and repaired or replaced as needed, and the master meters are calibrated annually. The entire water system must be surveyed for leak detection at least every two years, according to BWD's permit. Water conservation measures also include using water saving plumbing devices in public buildings and an education program to inform customers of the benefits of water conservation. Since 2002, BWD has instituted an increasing block-rate fee structure. As of May 15, 2002, BWD had implemented a mandatory restriction on outdoor (odd/even watering during specific times) water use in response to drought conditions. BWD allocates staff time to enforce these water use restrictions.

BWD also reported their unaccounted for water in 2001 as 8% of the total water supply, which is below the state's water conservation goal of less than 10%. Over the three years from 1999-2001, BWD's unaccounted for water averaged 9%.

4.2.4 Inflow/Outflow Analysis

An inflow/outflow analysis was also performed for the service area of Byfield Water District. Prior to 1998, all water withdrawn by BWD was from the Larkin Street wells located below the Byfield USGS gage. In September, 1998, BWD started withdrawing water primarily from the Forest Street well which is located above the USGS gage. As previously stated, our analysis of BWD's water distribution patterns shows that approximately 21% of all water distributed by BWD is used above the gage, the remaining 79% is used below the gage. Likewise, the study area above the gage received a net gain of water each year prior to 1998 from sources below the gage (an average of 12.77 MGY from 1990-1998). Conversely, the study area above the gage showed a dramatic net loss of water each year when BWD switched to the Forest Street well above the gage. From 1999-2001, the study area lost an average of 50.17 MGY to areas downstream of the Byfield USGS gage.

To estimate evaporative losses, it was assumed that 75% of water use is returned to the drainage area via septic systems, with the remaining 25% lost to evapotranspiration and consumptive use. Shown in Figure 4.2.4-1 is the estimated amount of water returned and lost from the area above the Byfield USGS gage, based on water withdrawals from the Forest Street well. Figure 4.2.4-2 shows the estimated amount of water returned and lost from the area above the Byfield USGS gage, based on water withdrawals from the Larkin Street well. Note the decrease in the withdrawals from this source after 1998. Water that was imported from GWD was not included in the analysis of BWD because it was accounted for in the inflow/outflow analysis for GWD.

4.3 Georgetown Sand and Gravel

Permit No.: 9P-3-16-105.02

The Georgetown Sand and Gravel Company (GSG) is a sand and gravel operation that withdraws water for processing directly from the Parker River in Georgetown. The current Water Withdrawal Permit, which became effective on August 23, 1996, authorizes a daily average withdrawal of 0.57 MGD (207 MGY). Water withdrawals on any given day are not to exceed 1.44 MGD. Water is withdrawn directly from the Parker River and is discharged into settling ponds, just downstream of the original withdrawal point, from which it seeps back to the river. It is assumed that the only water losses are evaporative.

There are no water use statistics available for the years 1994-1995 and the data available from 1990-1993 is only an estimated computation of historical withdrawal volume by GSG. It appears that the most reliable water use data is contained on the Registered & Permitted Withdrawals Annual Report for the years 1996-2001. GSG is reportedly discontinuing their operation in the near the future.

4.3.1 Annual and Monthly Withdrawal Volumes

Shown in Table 4.3.1-1 is the annual total withdrawal volume (MGY) and average daily withdrawal (MGD) for the period 1990-1993 and 1996-2001. As previously mentioned, the data from 1990-1993 is only an estimate, but has been included. The annual withdrawal volume decreases ranging from 0.52 MGD in 1997 to 0.18 MGD in 2001.

Table 4.3.1-1: Georgetown Sand and Gravel Company: Annual Withdrawal Summary

Year	Annual Withdrawal (MGY)	Average Daily Withdrawal (MGD)
1990	195.5	0.54
1991	196.5	0.54
1992	197	0.54
1993	197.5	0.54
1994	No Data	No Data
1995	No Data	No Data
1996	177.3	0.48
1997	189.9	0.52
1998	120.34	0.33
1999	144.33	0.40
2000	107.5	0.29
2001	65.45	0.18

GSG appears to slow operations in the months of January through March; for the rest of the year their water use remains fairly consistent. Shown in Figure 4.3.1-1 is a bar graph depicting the monthly water withdrawals by GSG from 1996-2001; 1990-1993 was excluded due to the fact that that these data were approximated. The monthly water usage is lowest in February at 3.6 MG, but remains consistently higher through the summer and fall with an average high in June of 14.0 MG.

4.3.2 Water Conservation Measures/Unaccounted for Water

Water conservation measures included in Georgetown Sand and Gravel's conservation plan include an employee awareness program. Also in the plan, several potential water conservation practices were adopted including opportunities to reuse process water onsite, installation of water efficient machinery, and efforts to adopt a closed loop system. Industrial water users are not required to report unaccounted for water on their annual reports.

4.4 G-town Produce

Registration No.: 3-16-105.02

Little information is available from MDEP concerning the water withdrawals of G-Town Produce. G-town Produce transferred their water withdrawal registration from Lakeridge Tree Farm of the same address on March 26, 1996. The permit authorizes an average withdrawal of 0.10 MGD from Rock Pond in Georgetown, which is located above the Byfield USGS gage. G-town Produce is authorized to withdraw water for their operation for 184 days per year. An annual report from 1991 obtained from MDEP indicated that most of the irrigation water is taken from Rock Pond during the months of June through September. No other data is available to evaluate their withdrawal.

4.5 Water Withdrawal Trends

Annual water use seems to be increasing most dramatically in the town of Georgetown as compared to the other major water withdrawals in the Parker River Basin above the Byfield USGS gage. Average daily consumption for GWD, BWD, and GSG were compared for the period 1990-2001. Figure 4.5-1 illustrates a 48% and 14% increase of water use by GWD and BWD, respectively for the period 1990-2001. Figure 4.5-1 also shows the decrease in water use by Georgetown Sand and Gravel, which may reflect changes in water use reporting methods and not an actual drop in water use.

Figure 4.5-2 depicts the average monthly withdrawals in the Parker River basin above the Byfield USGS gage by GWD, BWD and GSG relative to the average monthly flow recorded at the Byfield USGS gage from 1990-2001. The total average withdrawal in millions of gallons were converted to cubic feet per second (cfs). Average withdrawals for BWD are displayed for the period when they switched to the Forest Street Well upstream of the gage as their major withdrawal point (Sept. 1998-end of 2001). The percentages associated with each column in Figure 4.5-2 indicate the amount of water withdrawn in cfs relative to total stream flow. As the graph depicts, water withdrawals tend to increase in the summer months when the river flows are on average the lowest. The critical period is in July, August and September, where the average proportion of water withdrawn relative to streamflow is 31%, 40% and 25%, respectively (average for 1990-2001 period).

The cumulative effect of water withdrawals for each year was further investigated by evaluating withdrawals in relation to the amount of stream flow for each year from 1990-2001. These trends are illustrated in Figures 4.5-3 through 4.5-14. These results indicate that in drier years such as 1995, 1997, and 2001, the total withdrawal volume exceeds the Parker River flow. In 1995 GWD's total water withdrawals alone were 307%, 1,150%, 1,052% greater than the average monthly flow measured at the Byfield USGS gage for the months of July, August, and September, respectively (see Figure 4.5-8). In 1997, during the months of July, August, and September, GWD's and GSG's water withdrawals in the study area are 309%, 1,526%, and 1,641% greater, respectively, than the average monthly flow measured at the Byfield USGS gage (see Figure 4.5-10). In 2001, this situation even carried over into the months of October and November when total water withdrawals from all three major users exceeded average monthly streamflow by 911% and 193%, respectively.

An important factor to consider when reviewing these figures is the amount of precipitation the basin received during a particular month. For example, the low flows observed in 1995 and 1997 occurred when there was very little precipitation in the basin during the summer months. The low precipitation contributed to lower stream flows, however water demand remained high in the summer. GWD withdrawals in July 1997 were 34.29 MG while total precipitation was 1.81 inches. In contrast, the GWD withdrawals in July 1996 were 24.11 MG while total precipitation was 6.68 inches. During these two months, withdrawals from GSG were identical (17.1 MGM). Figure 4.5-15 shows the relationship between precipitation and water withdrawals for the months of June, July, and August during the period 1990-2001. The slope of the regression line provides an indication as to whether the trend showed a increase (positive slope) or decrease (negative slope) over the respective period of record. The water withdrawals depicted consist of those made by GWD and BWD. The regression lines on Figure 4.5-15 show an overall trend of increasing water withdrawals with decreasing precipitation, suggesting that outdoor water use and residential irrigation increases when precipitation diminishes.

The fact that the two major water suppliers in the basin above the Byfield USGS gage do not have long-term storage capacity (such as storage reservoirs) exacerbates conditions when there is little precipitation. The suppliers are unable to limit withdrawals when demand is the highest because there is not enough storage capacity built into their systems to sustain normal system demand for more than a day or two.

4.6 Evaluation of Summer 1997: Daily Water Withdrawals, Precipitation, and Streamflow

1997 ranked as the 17th driest year (out of 57 years total) in terms of total annual streamflow and the 11th driest year in terms of total annual precipitation (out of 57 years total). In addition, the summer (June 1 to September 30) of 1997 ranked as the 9th driest on record in terms of streamflow. The Parker River Clean Water Association (PRCWA) documented several desiccated reaches of the Parker River in Georgetown during the summer of 1997 (PRCWA 2001). Using several parameters, this particularly dry summer period was examined in more detail below.

Figure 4.6-1 illustrates the average daily water withdrawals made by GWD and BWD, daily precipitation, and average daily streamflow from the Byfield USGS gage. The spring of 1997 was characterized by relatively high flows; however, flow began to steadily decline throughout June. On July 13th, streamflow at the Byfield gage fell below 1.0 cfs and remained below this level until November 3rd. Water withdrawals experienced some day-to-day variability, but were generally highest during June and July, before beginning to decline in mid-August. In terms of precipitation, both June and July ranked in the 20th percentile for total individual monthly precipitation. The month of August experienced slightly more precipitation (57th percentile); however, dry conditions returned in September (29th percentile) and October (9th percentile). Based on the interaction between water withdrawal and precipitation amounts shown in Figure 4.6-1, it appears that most precipitation events resulted in an immediate decrease in water withdrawals. In addition, Parker River flows did not respond appreciably to these precipitation events.

4.7 Other Water Withdrawals and Summary of Non-Registered Public Water Withdrawals

There are other water withdrawals within the Parker River watershed above the Byfield USGS gage. These withdrawals consist of numerous private wells, as well as other non-registered and non-permitted (less than 100,000 gallons per day) public water withdrawals. Table 4.7-1 depicts non-registered public water withdrawals within the Parker River watershed above the Byfield USGS gage. The location of these withdrawals is also shown in Figure 4.0-1. However, since the withdrawal volumes at these other sites are less than 100,000 gallons per day, no registration or permit is required; in most cases the actual withdrawals are not measured. The cumulative effect of these withdrawals on the Parker River flow regime is unknown, but it is likely significantly less than that of the larger uses.

Table 4.7-1: Non-Registered Public Water Withdrawals within the Parker River Watershed above the Byfield USGS Gage

Source Code	Site Name	Location
3038008-01G	Spofford Pond School	Boxford
3038015-01G	Camp Denison	Georgetown
3038023-01G	200 Washington Street	Boxford
3038010-01G	Village Store Building	Boxford
3038021-02G	Georgetown Limited Partnership Building	Boxford
3038025-01G	Second Congregational Church	Boxford

Most private household well withdrawals and the withdrawals listed in Table 4.7-1 are assumed to be relatively small in magnitude, and the majority of wastewater would be discharged back to the watershed system. A possible exception would be the Georgetown Country Club (GCC), which is located in the eastern portion of Georgetown on Route 133. Currently, MDEP has not required GCC to register their water use or measure withdrawals volumes. GCC was contacted to inquire about their water use as part of this study. GCC utilizes three wells for irrigation purposes only; all potable water is provided by GWD. One well has been in place for ten years, and the other two have been in use for about three years. Water is pumped into a pond on site, and then pumped to the golf course for irrigation of 37 acres. GCC uses irrigation water during the typical golfing season which is April through November.

GCC also provided estimated monthly water withdrawal data for the years 1997-1999 combined. There was no data available for 2000-2001. In 2002 a flow meter was installed to allow accurate data to be collected on monthly water usage. Table 4.7-2 represents the monthly water use for irrigation purposes by GCC.

Table 4.7-2: Monthly Water Use by Georgetown Country Club

Month	**1997-1999 Estimates (MGM)**	**Actual 2002 (MGM)**
April	0.39	0.48
May	1.55	1.38
June	3.88	1.77
July	3.88	3.21
August	3.88	3.18
September	1.55	2.34
October	0.39	0.16
November	0.00	0.40
Total	**15.50**	**12.92**

Figure 4.0-1: Water Withdrawal Locations within the Parker River Study Area

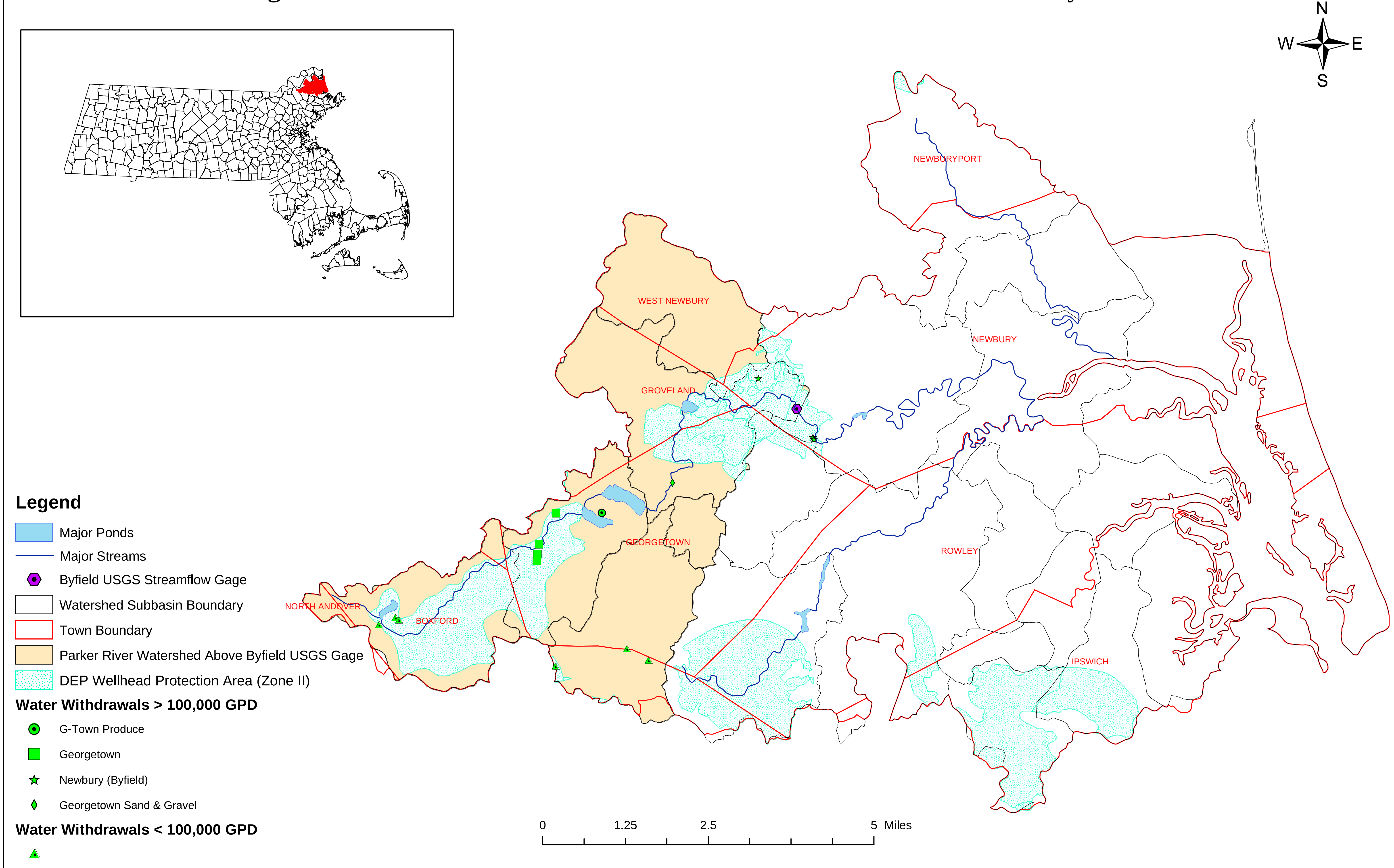


Figure 4.1.1-1: Georgetown Water Department: Average Monthly Water Withdrawals for the Period 1990-2001

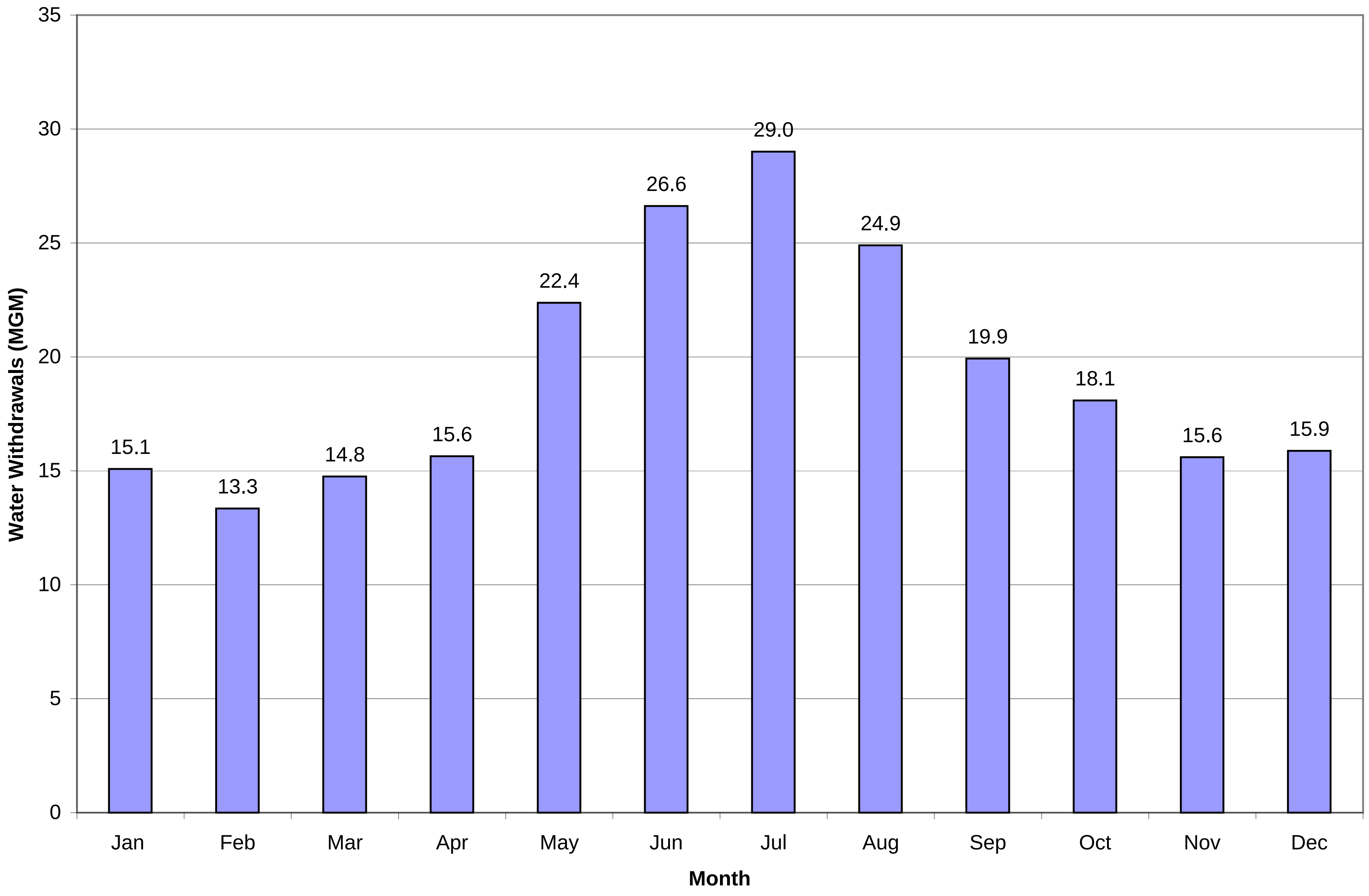


Figure 4.1.2-1: Georgetown Population and Total Water Withdrawals by GWD Summary, Period of Record 1990-2001

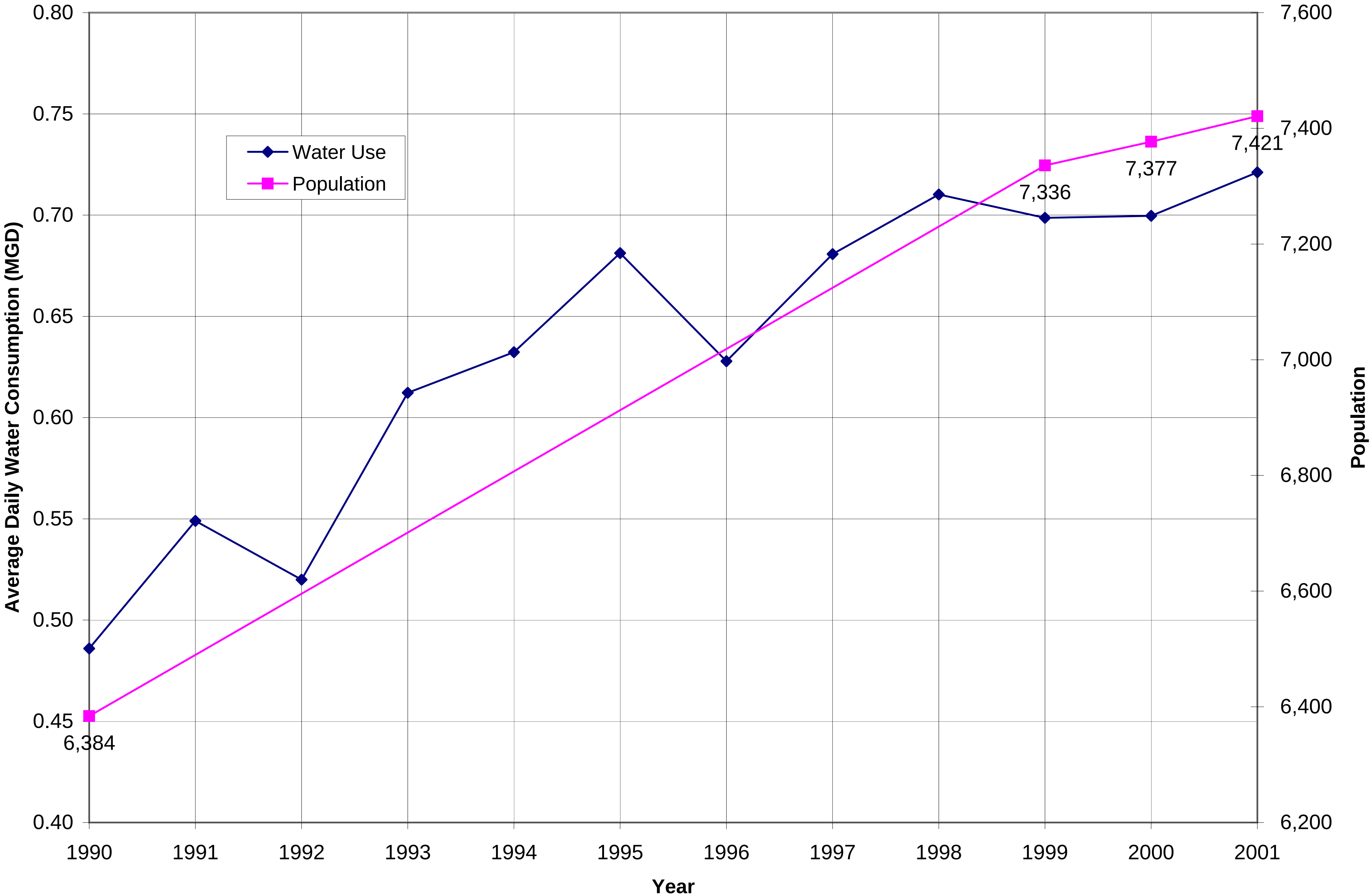


Figure 4.1.4-1: Georgetown Water Department - Annual Volume of Water Pumped from the Parker River Basin (Breakdown of estimated return and loss of water from the study area)

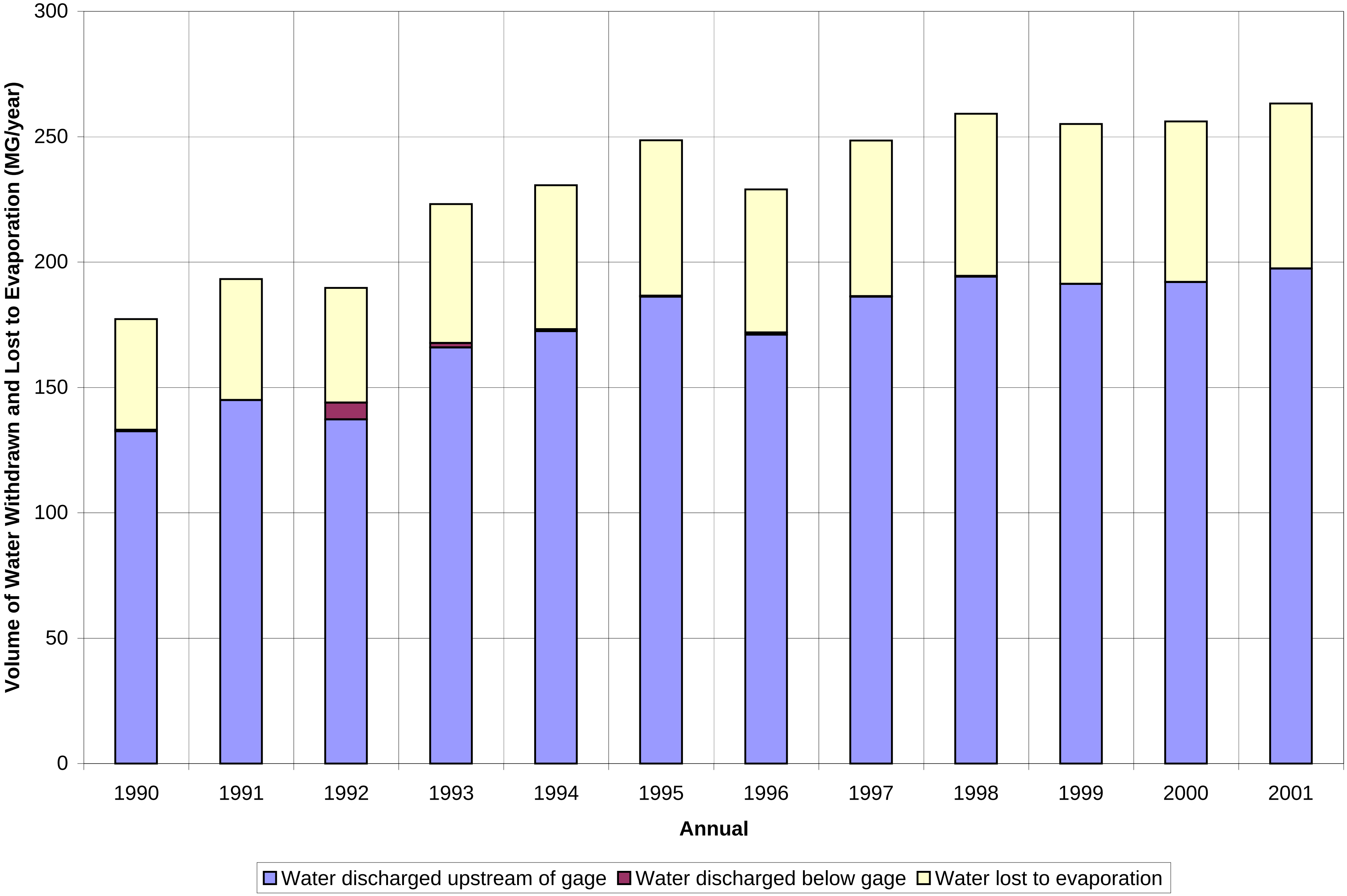


Figure 4.2.1-1: Byfield Water District: Average Monthly Water Withdrawals From All Sources for the Period 1990-2001

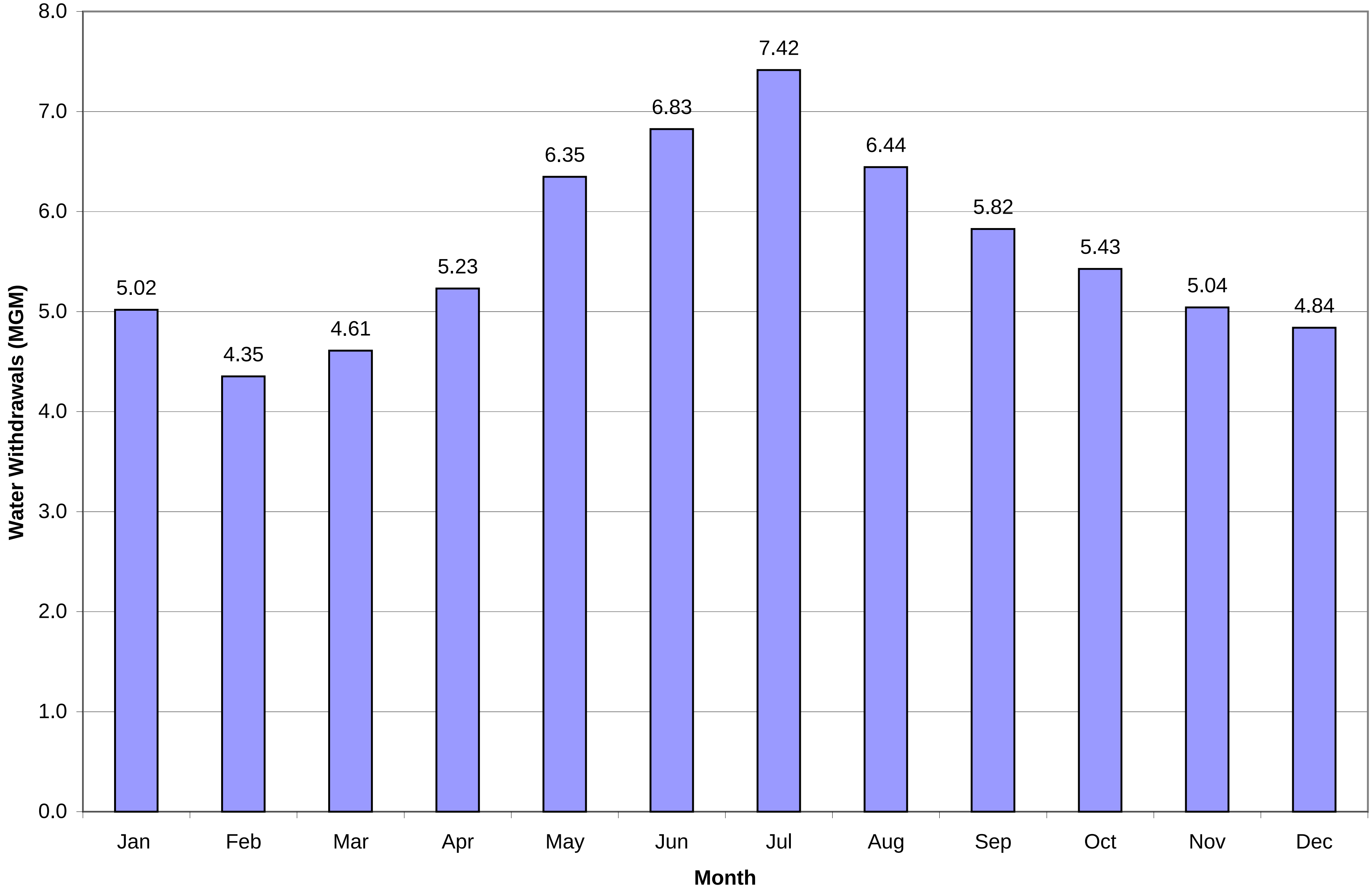


Figure 4.2.1-2: Byfield Water District: Average Monthly Withdrawals from the Forest Street Well (Above Gage) for the Period 1999-2001

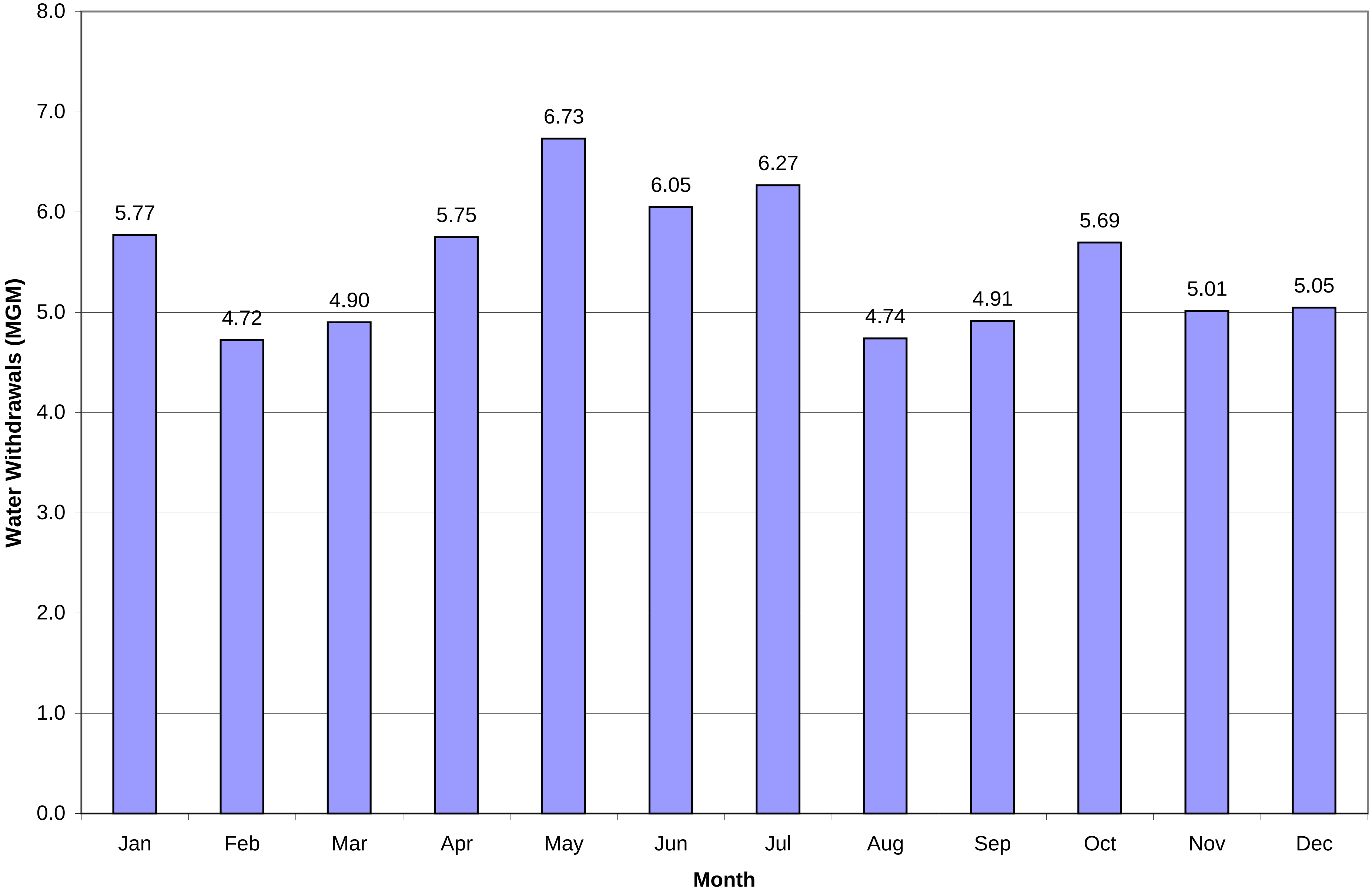


Figure 4.2.1-3: Byfield Water District: Average Monthly Water Withdrawals From All Sources for the Period 1999-2001

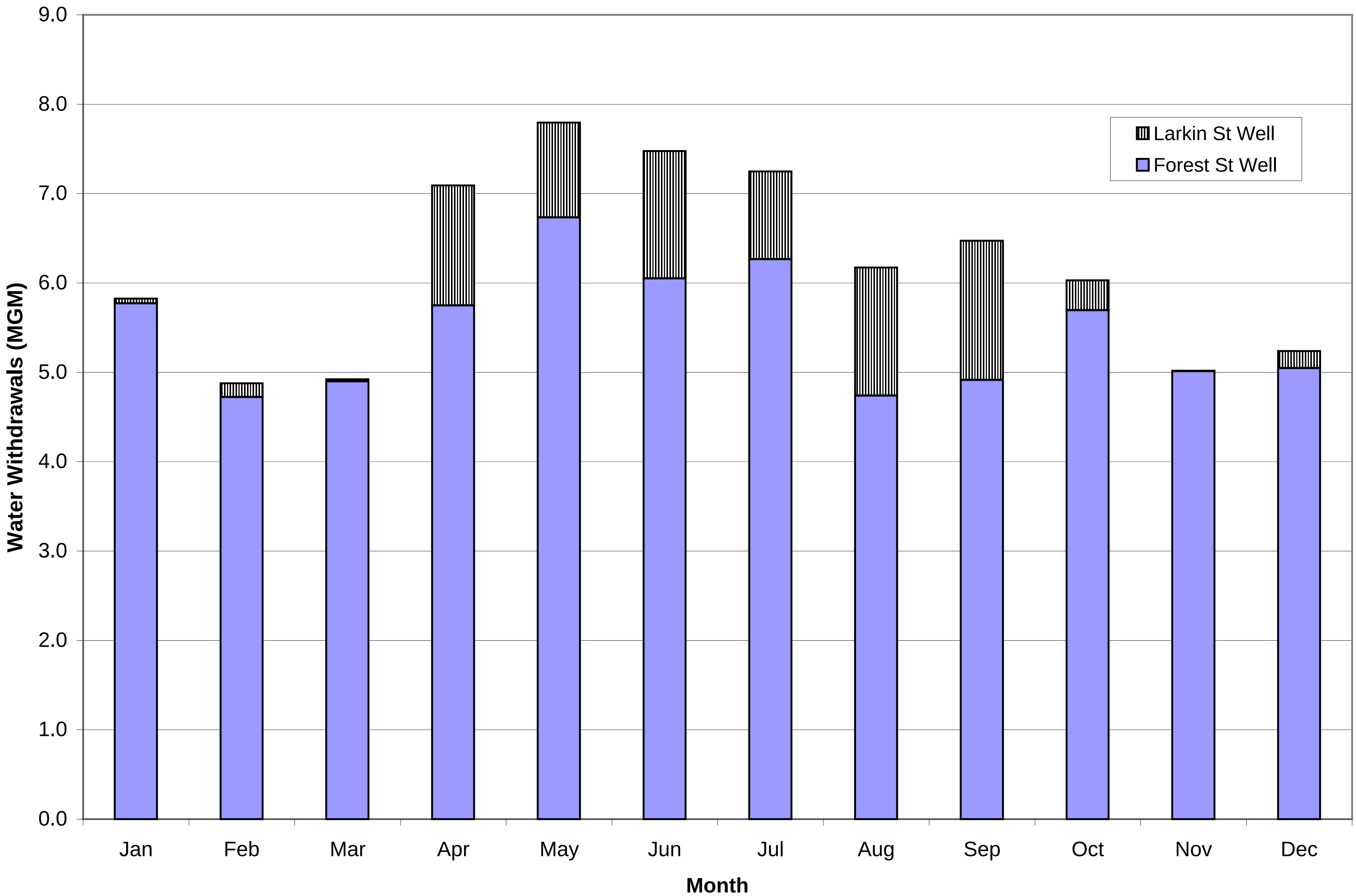


Figure 4.2.2-1: Byfield Service Population and Total Water Withdrawals by BWD (All Sources) Summary, Period of Record 1990-2001

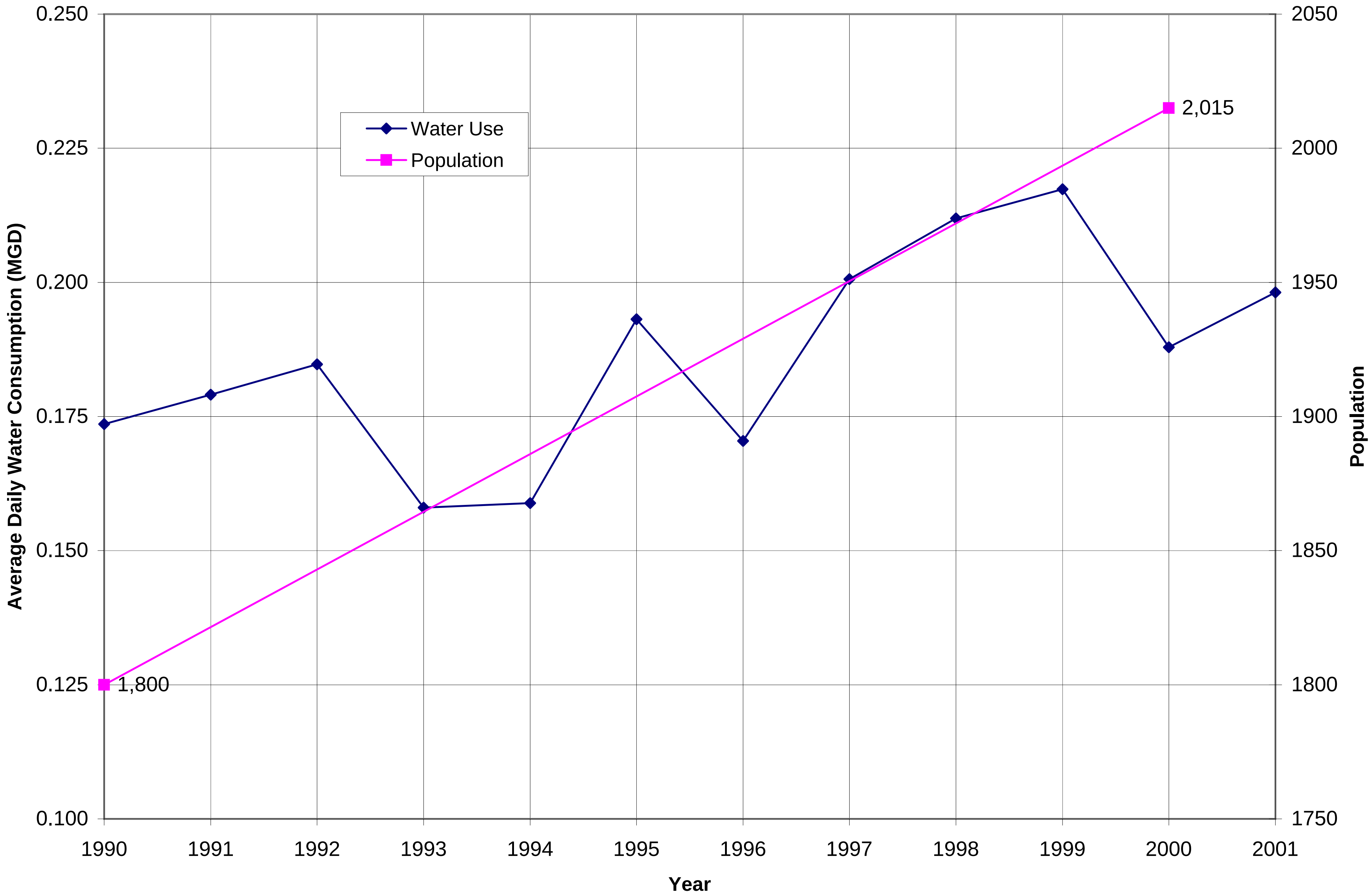


Figure 4.2.4-1: Byfield Water District - Annual Volume of Water Pumped from the Forest Street Well Above the USGS gage in Byfield (Breakdown of estimated return and loss of water from study area)

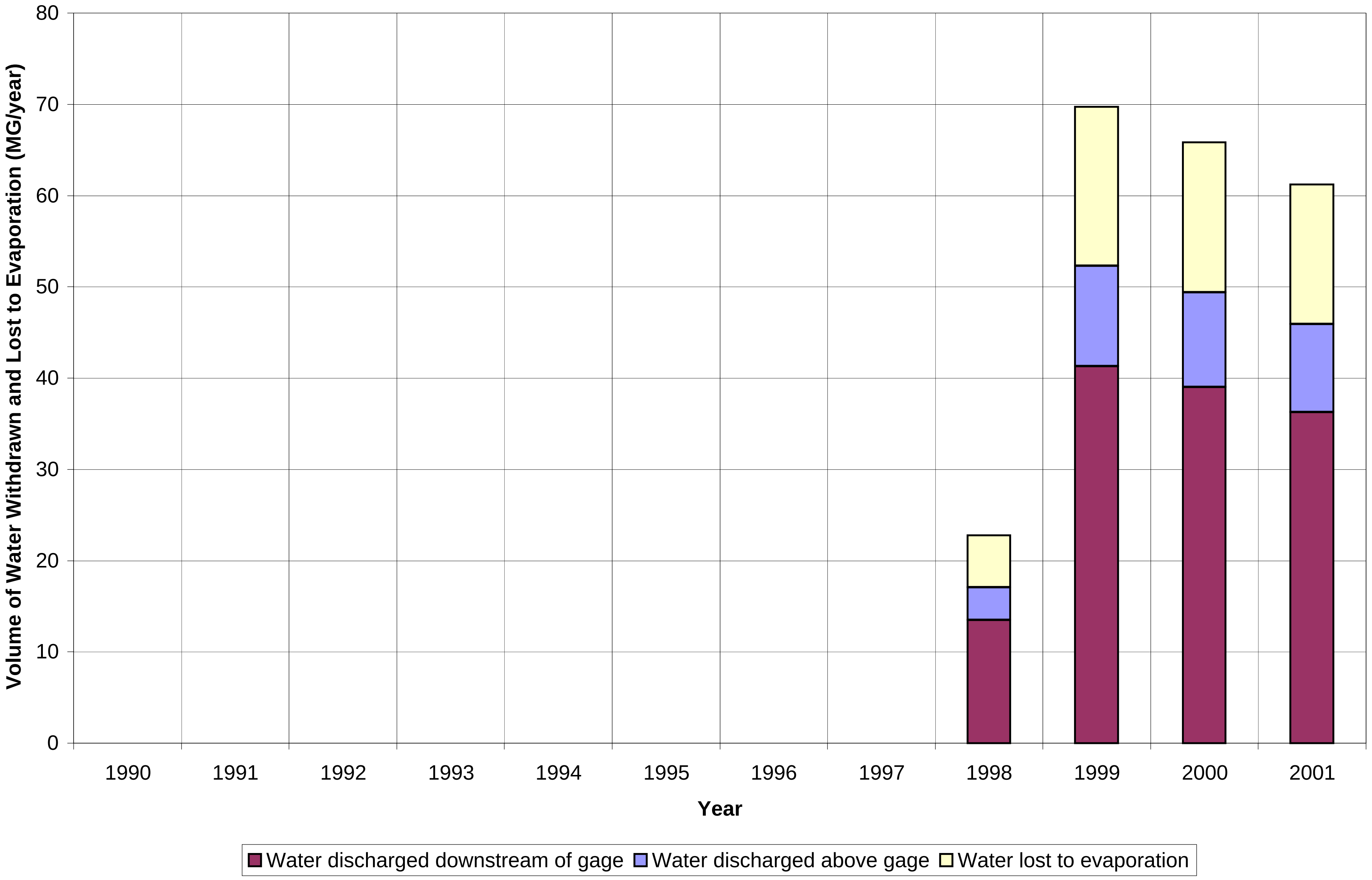


Figure 4.2.4-2: Byfield Water District - Annual Volume of Water Pumped from the Larkin Street Well Below the USGS gage in Byfield (Breakdown of estimated return and loss of water from study area)

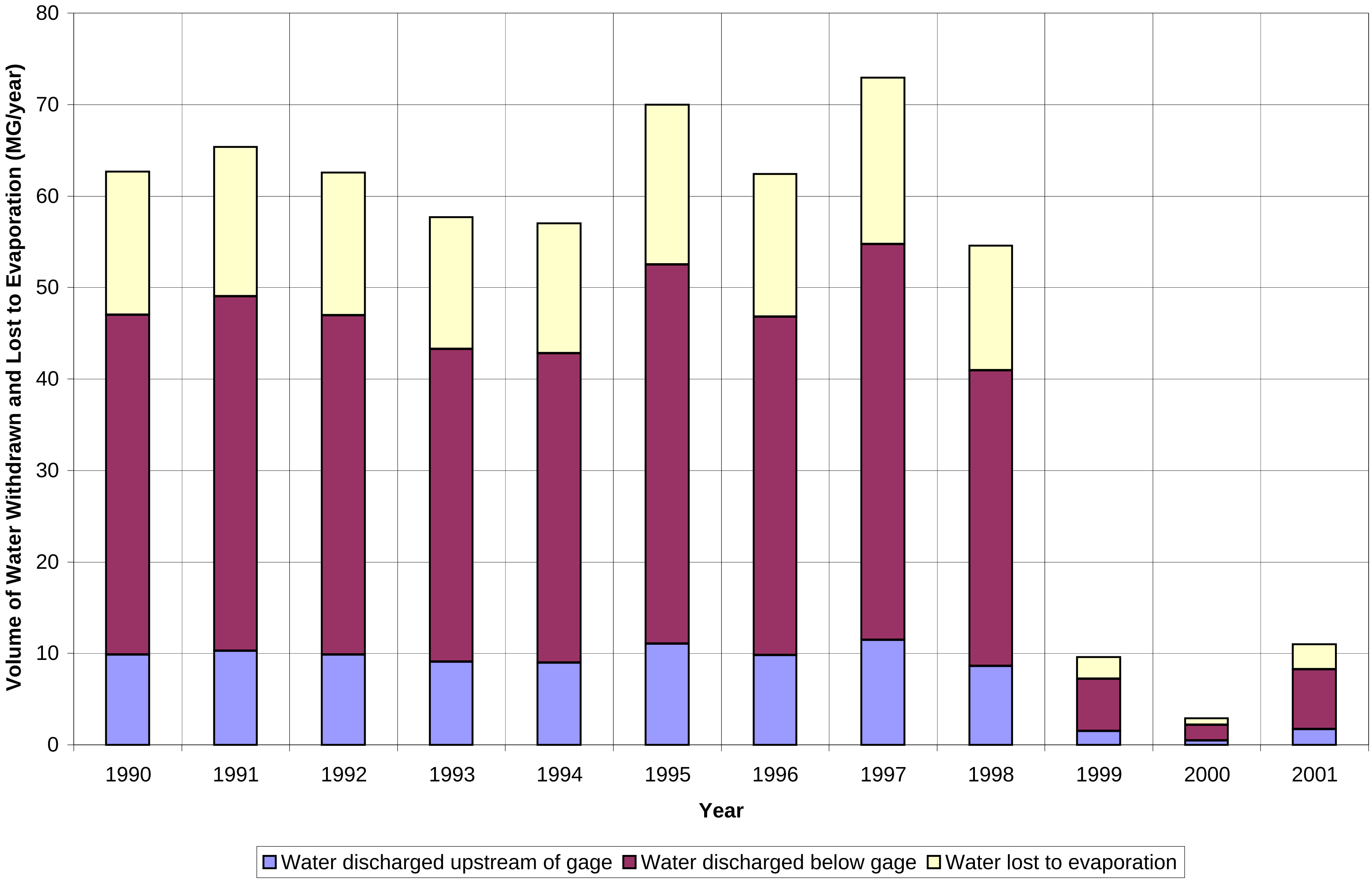


Figure 4.3.1-1: Georgetown Sand and Gravel Company: Average Monthly Water Withdrawals for the Period 1996-2001

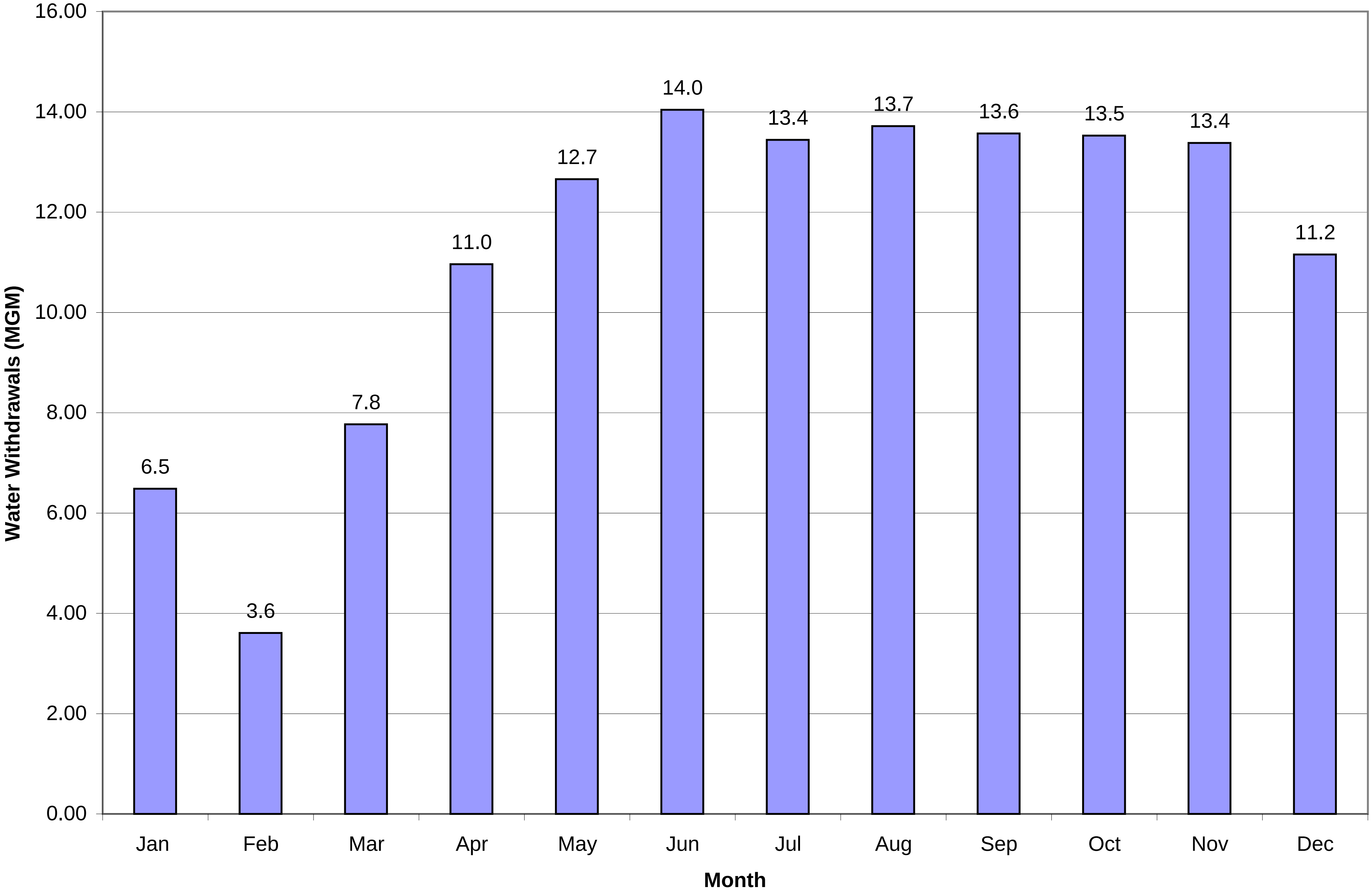


Figure 4.5-1: Average Daily Water Withdrawals for Georgetown Water Department, Byfield Water District and Georgetown Sand and Gravel Company, Period of Record 1990-2001

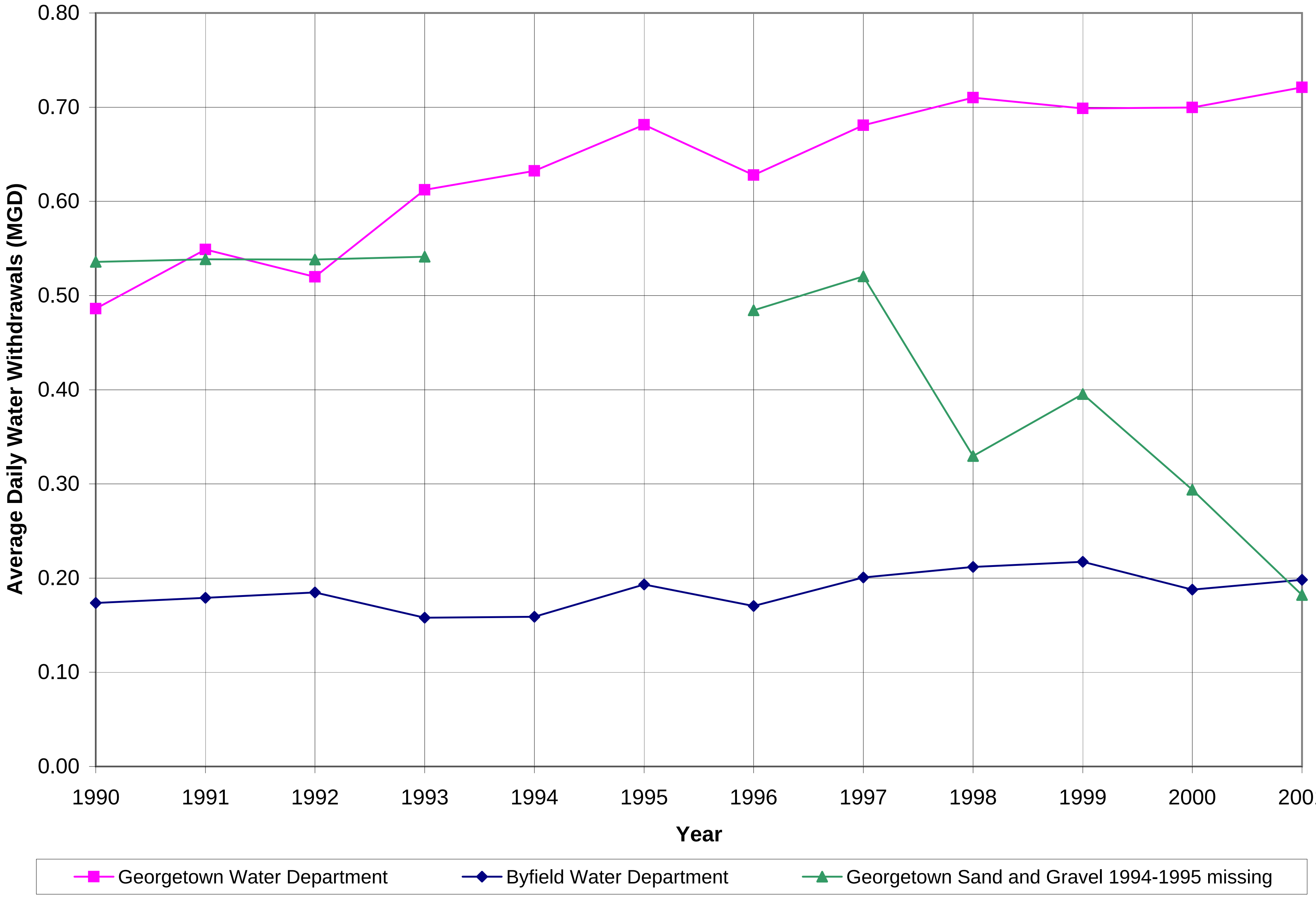


Figure 4.5-2: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1990-2001

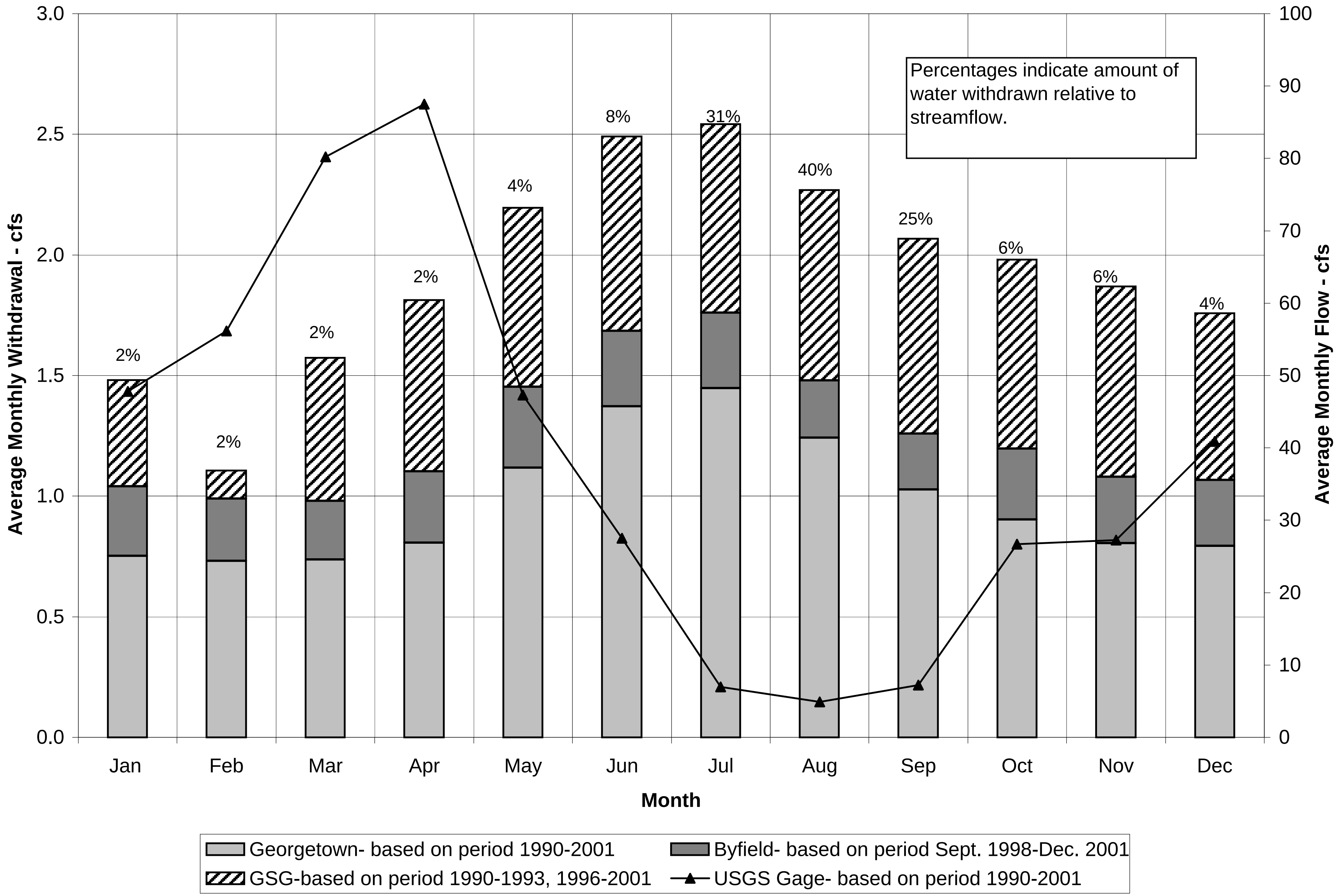


Figure 4.5-3: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1990

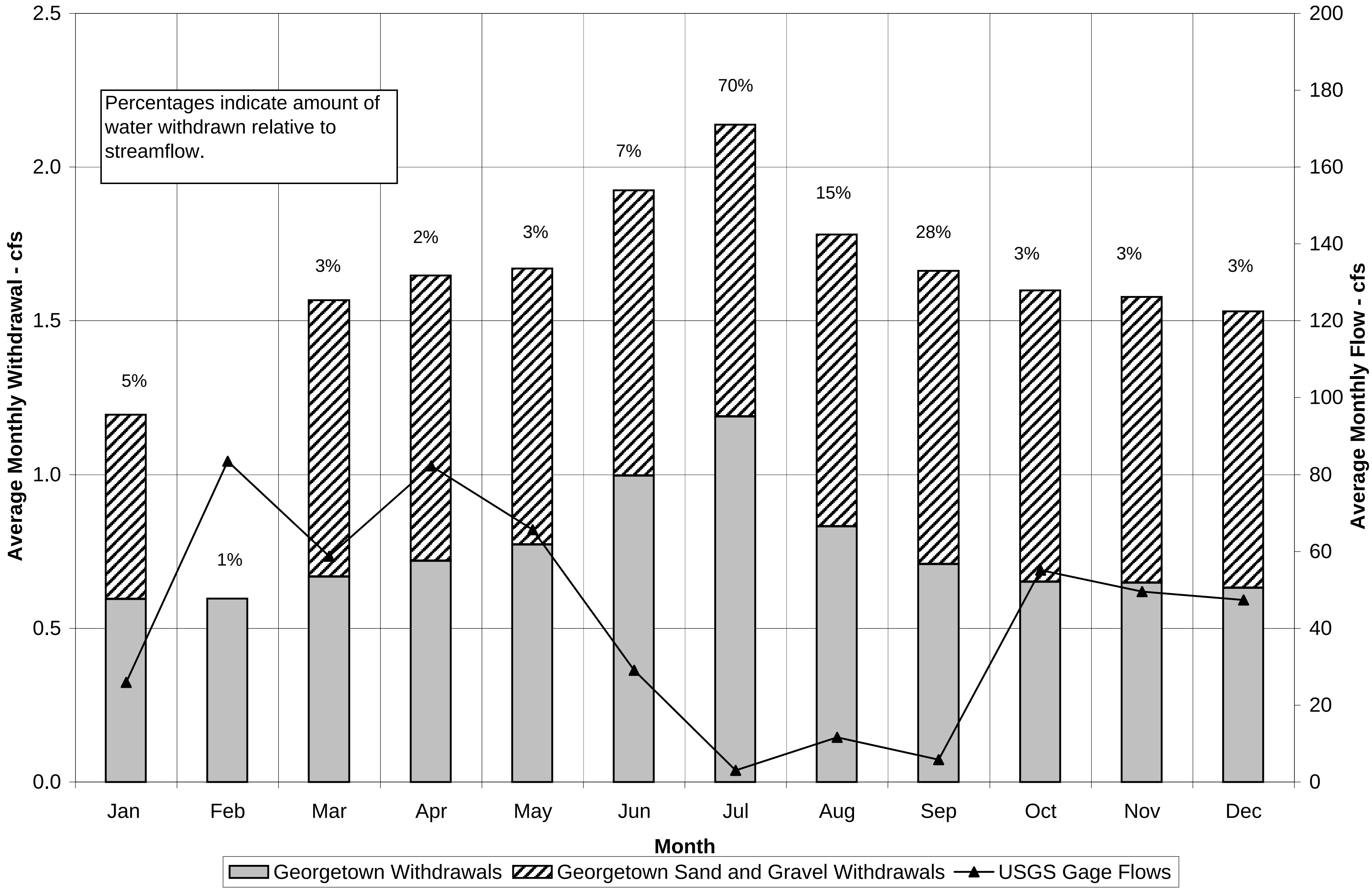


Figure 4.5-4: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1991

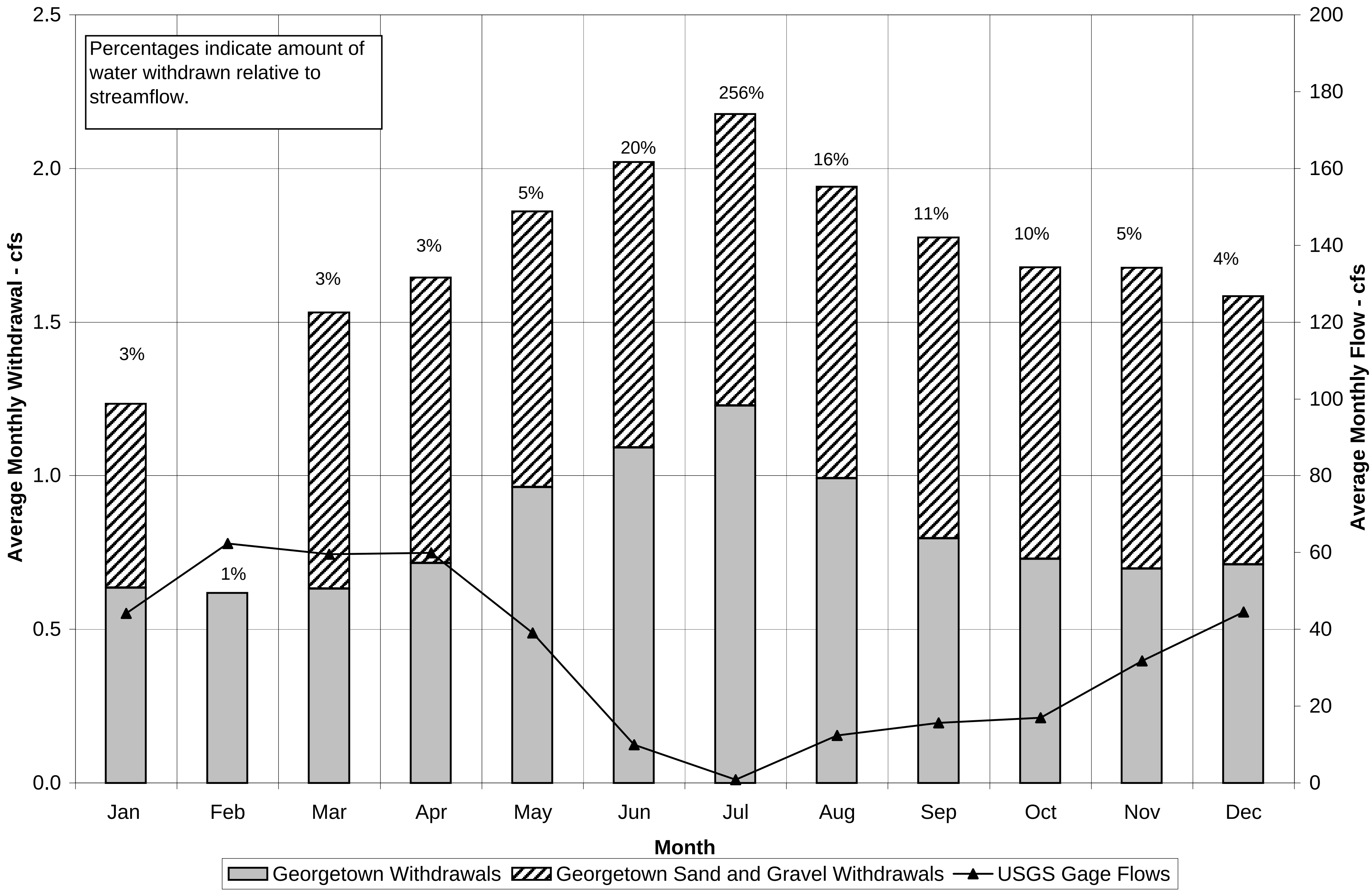


Figure 4.5-5: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1992

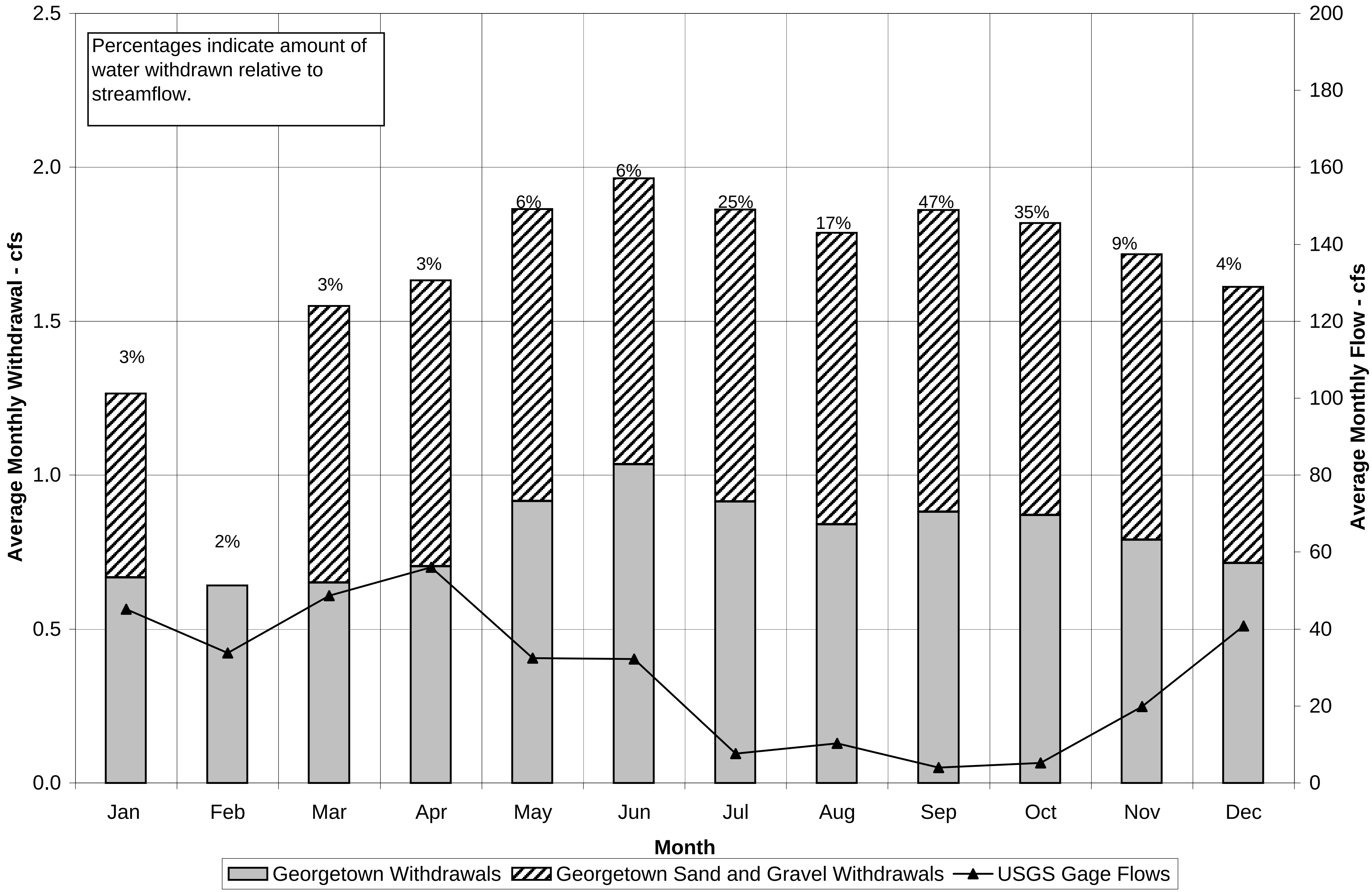


Figure 4.5-6: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1993

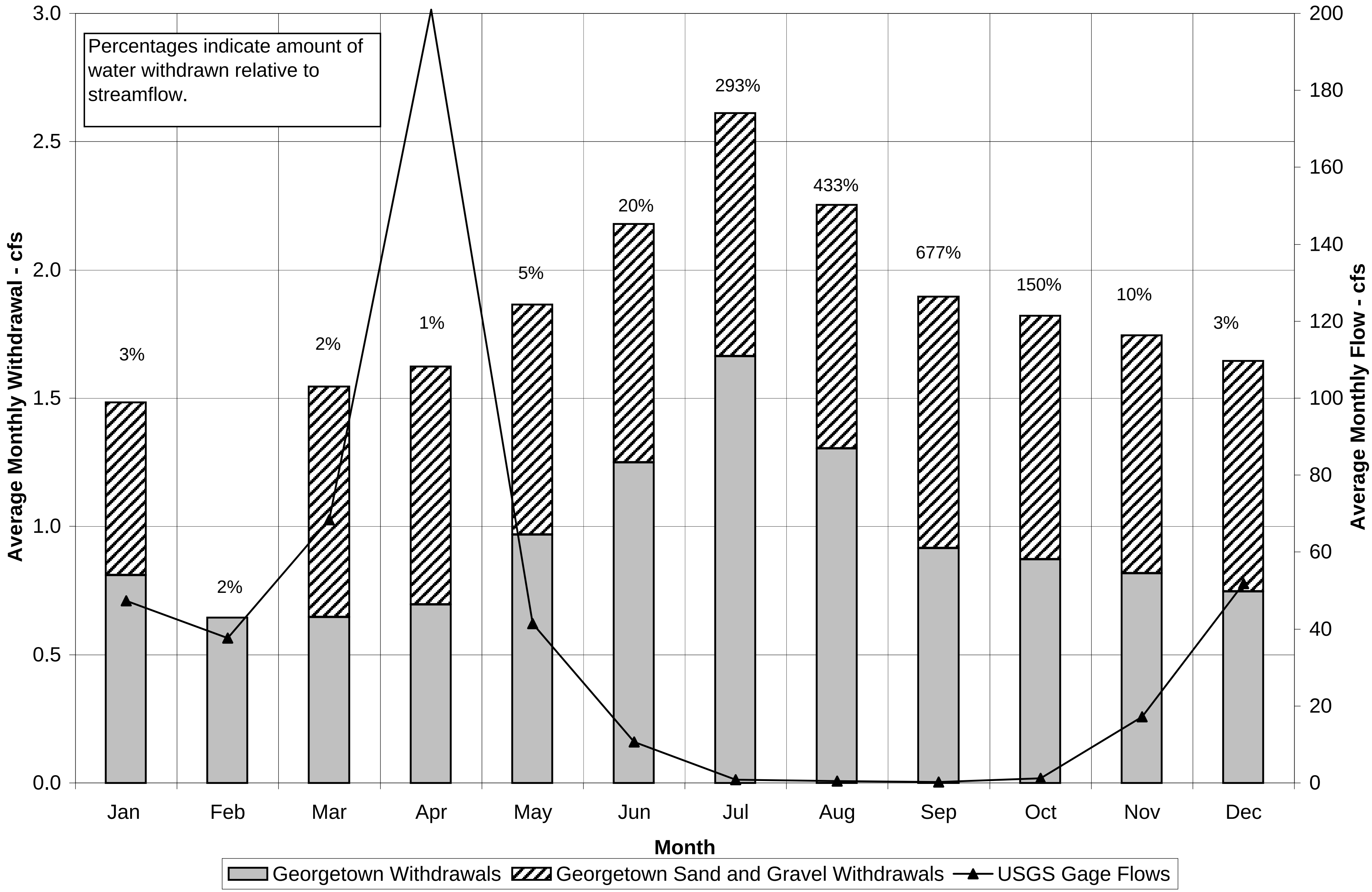


Figure 4.5-7: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1994

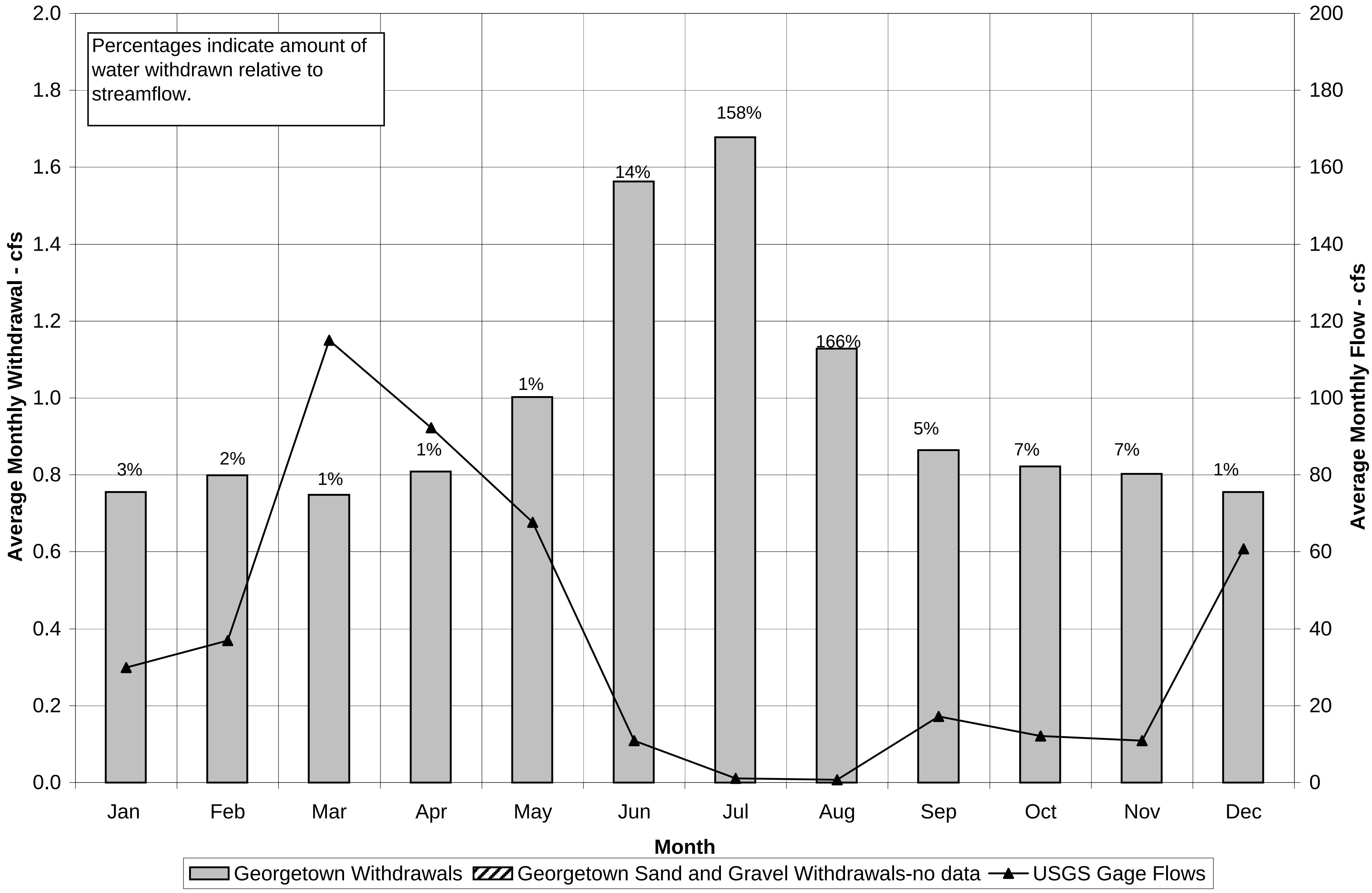


Figure 4.5-8: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1995

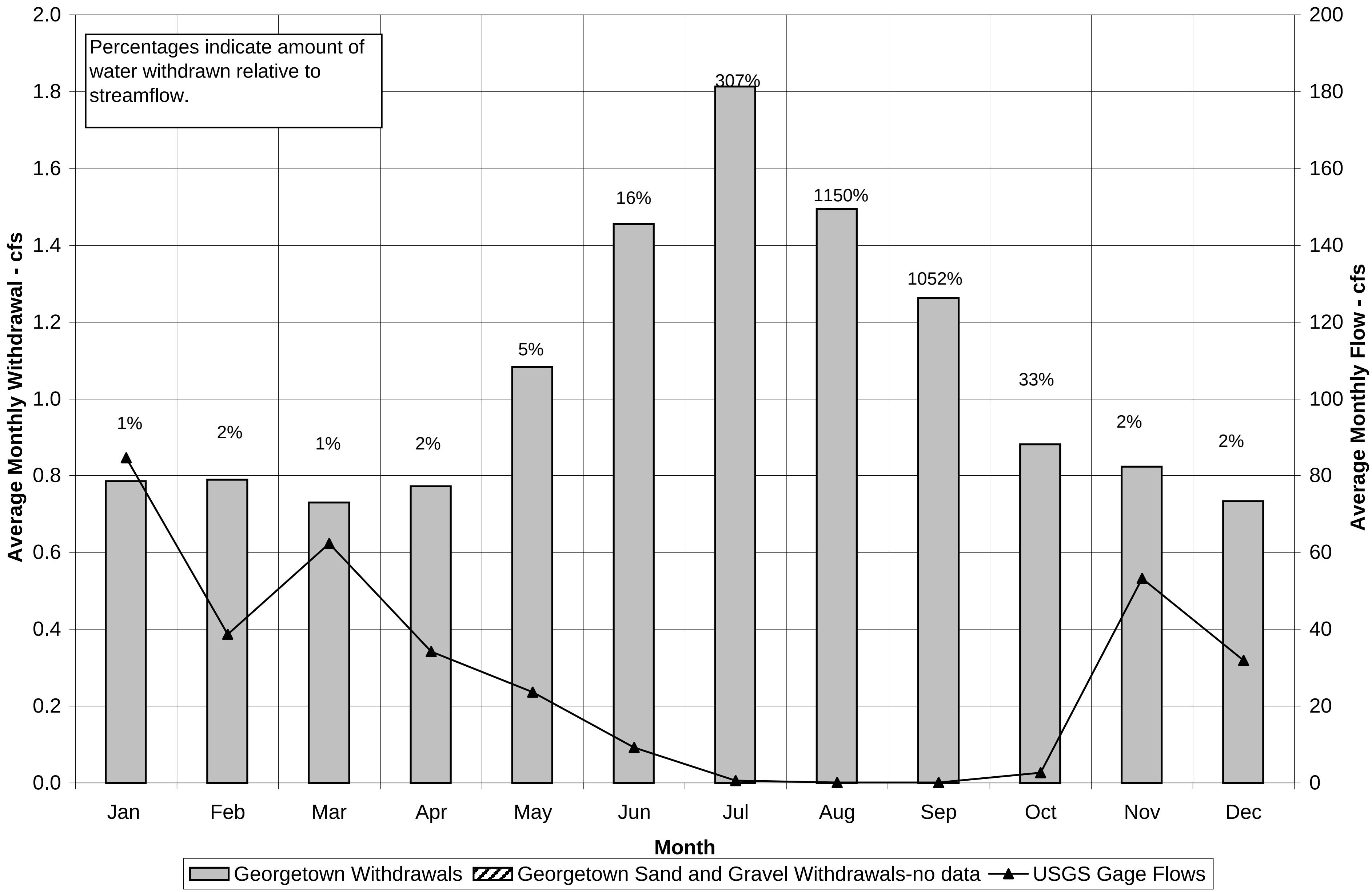


Figure 4.5-9: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1996

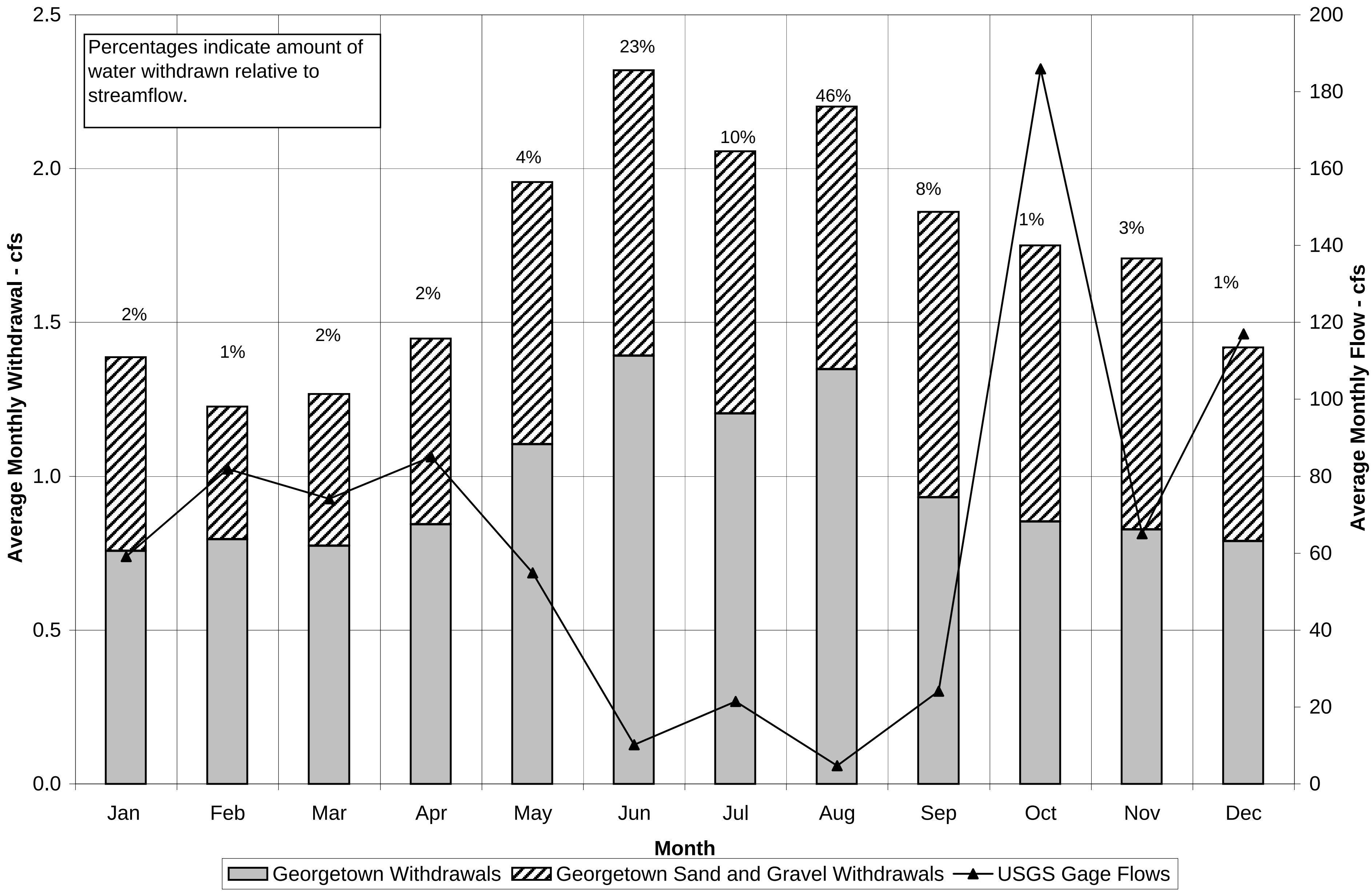


Figure 4.5-10: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1997

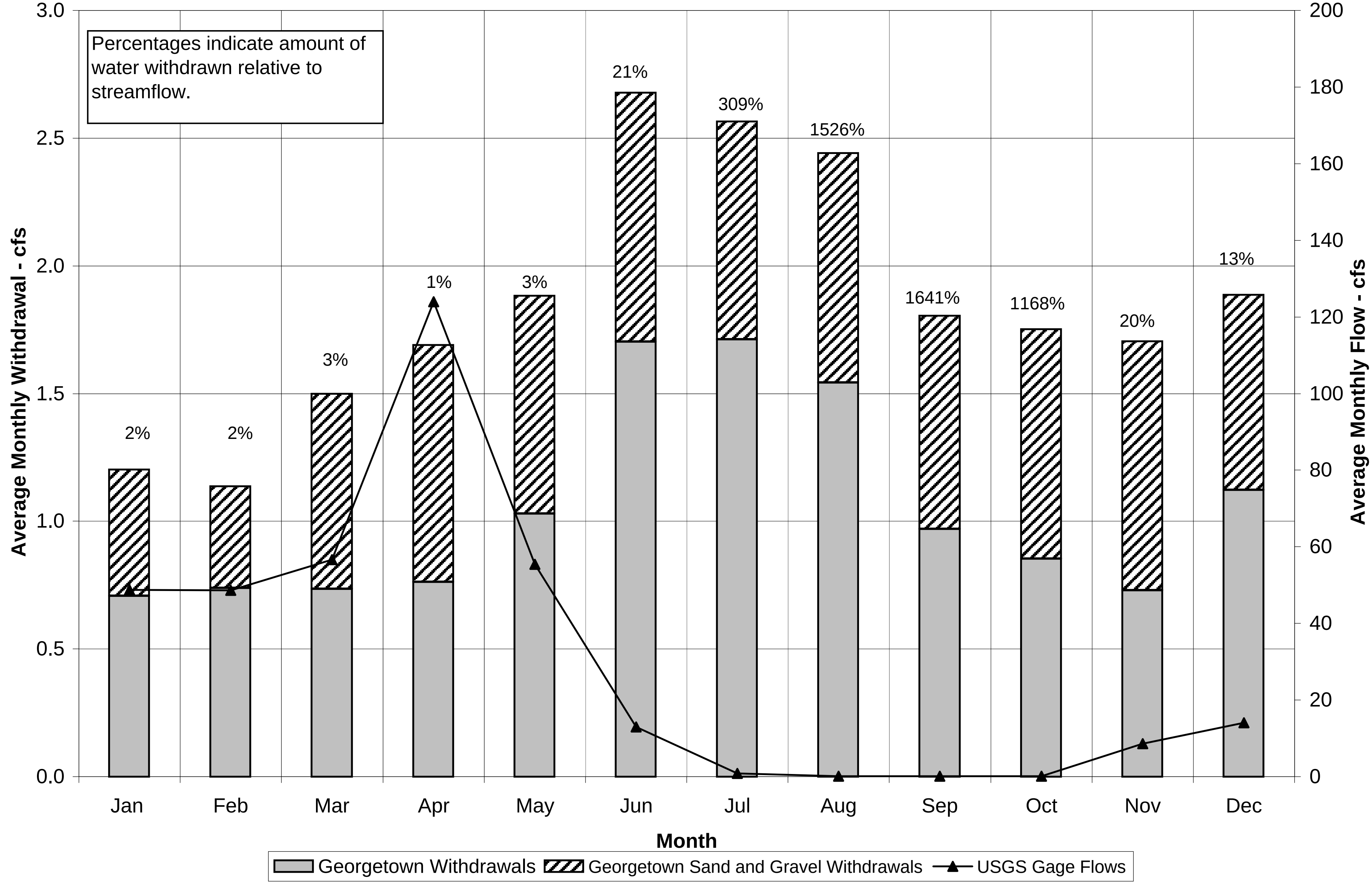


Figure 4.5-11: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1998

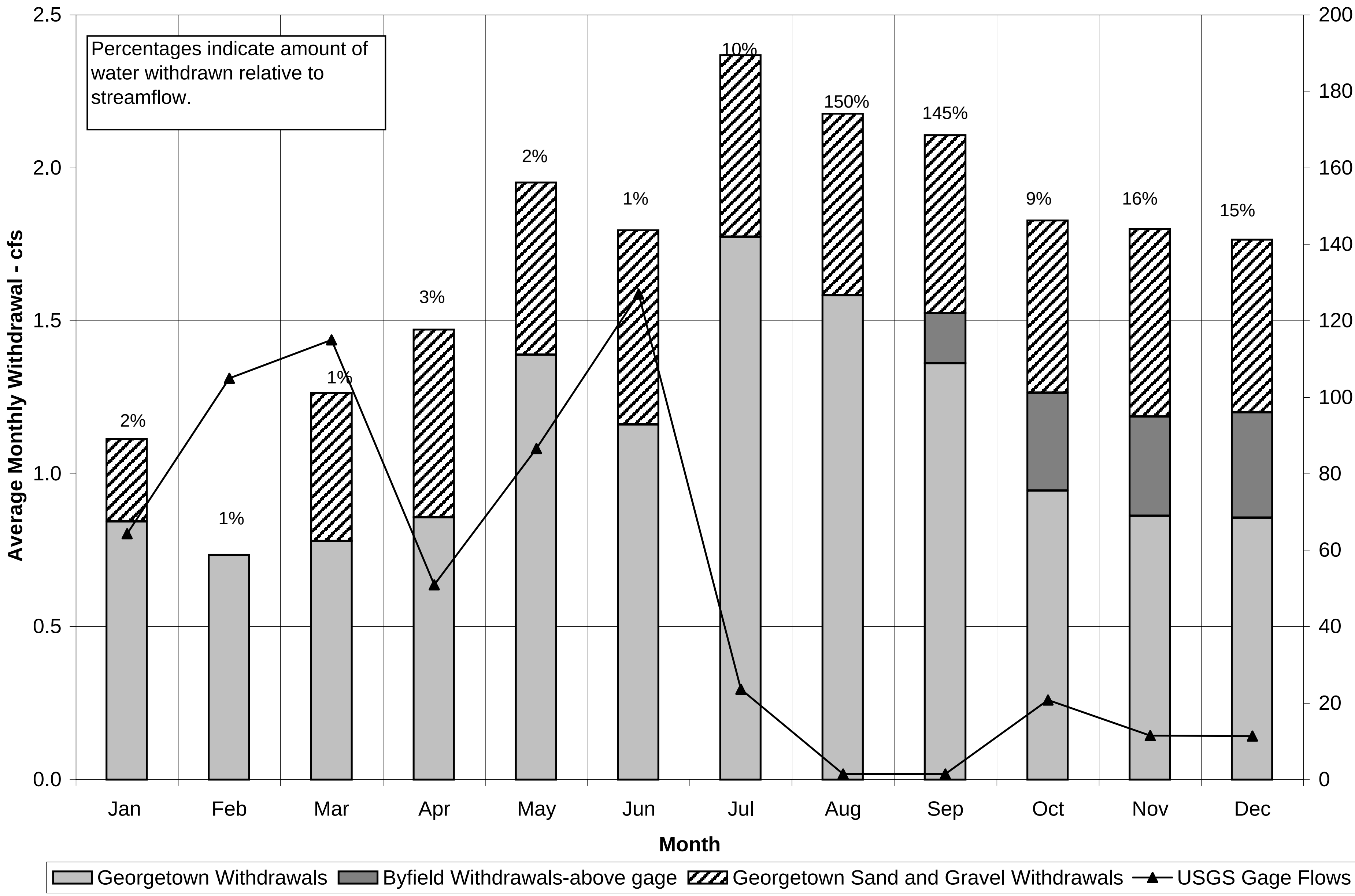


Figure 4.5-12: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 1999

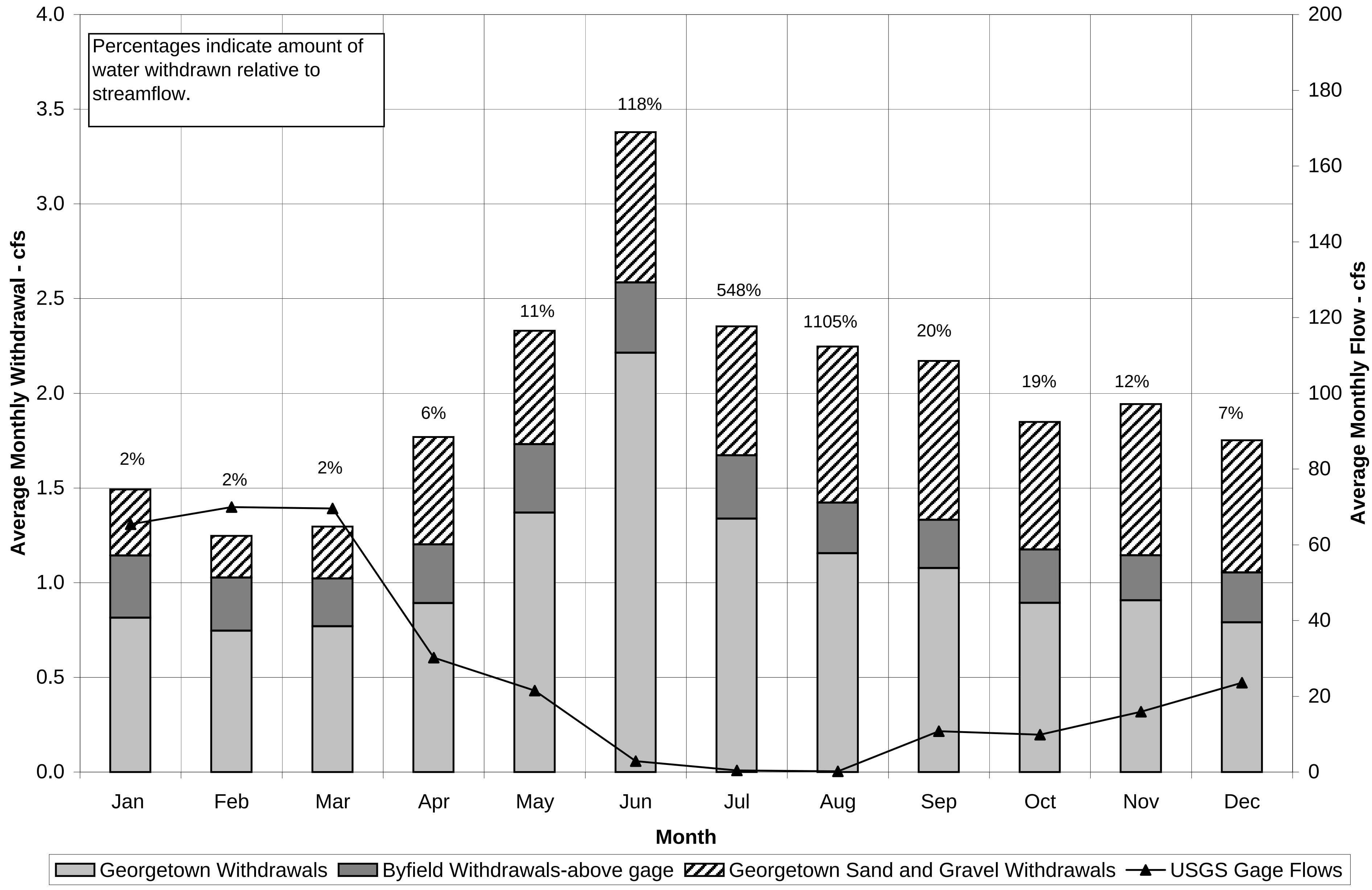


Figure 4.5-13: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 2000

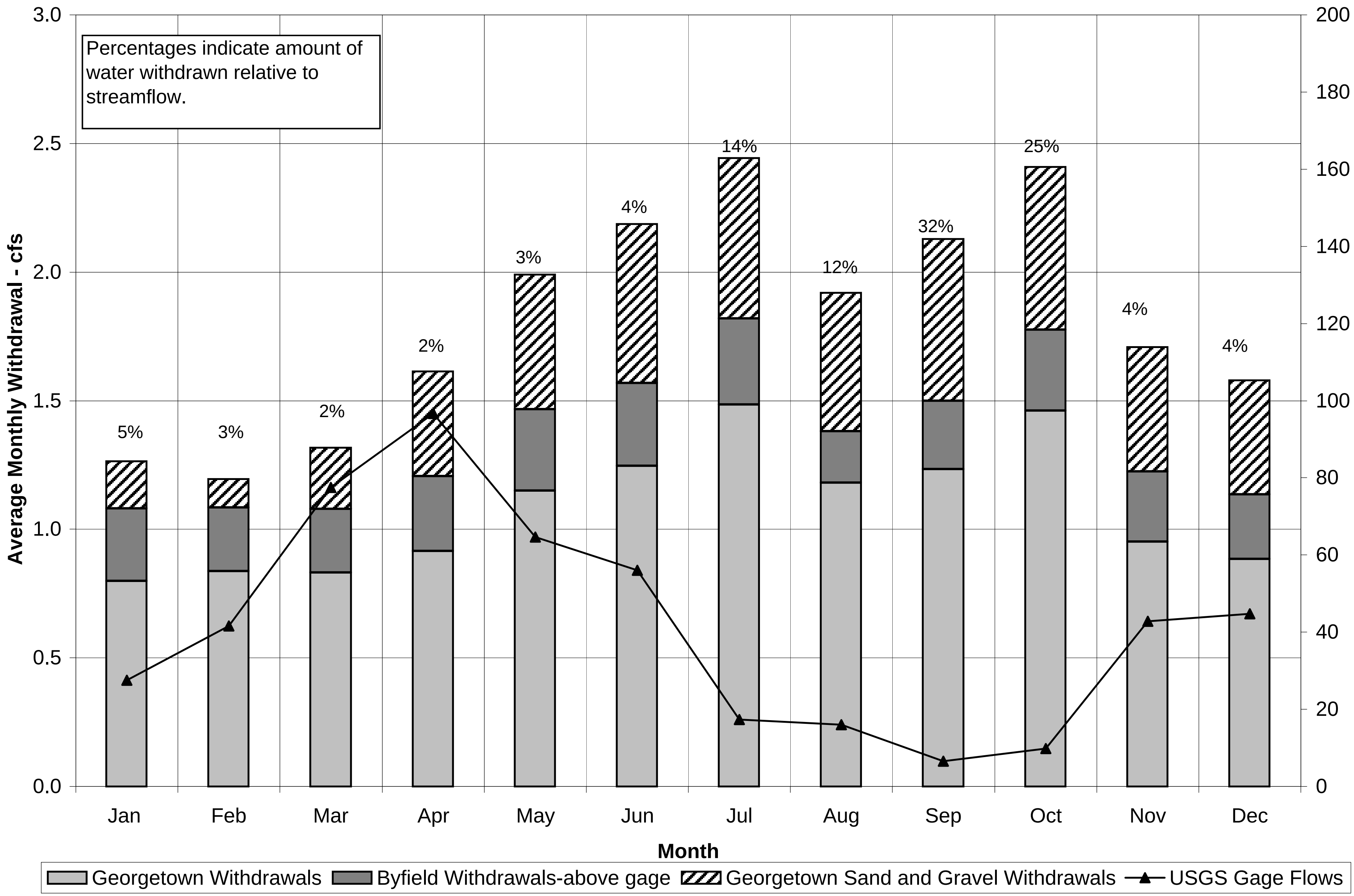


Figure 4.5-14: Average Monthly Withdrawals in the Parker River Basin Upstream of the Byfield USGS Gage versus Average Monthly Flow at the Byfield USGS Gage, Period of Record: 2001

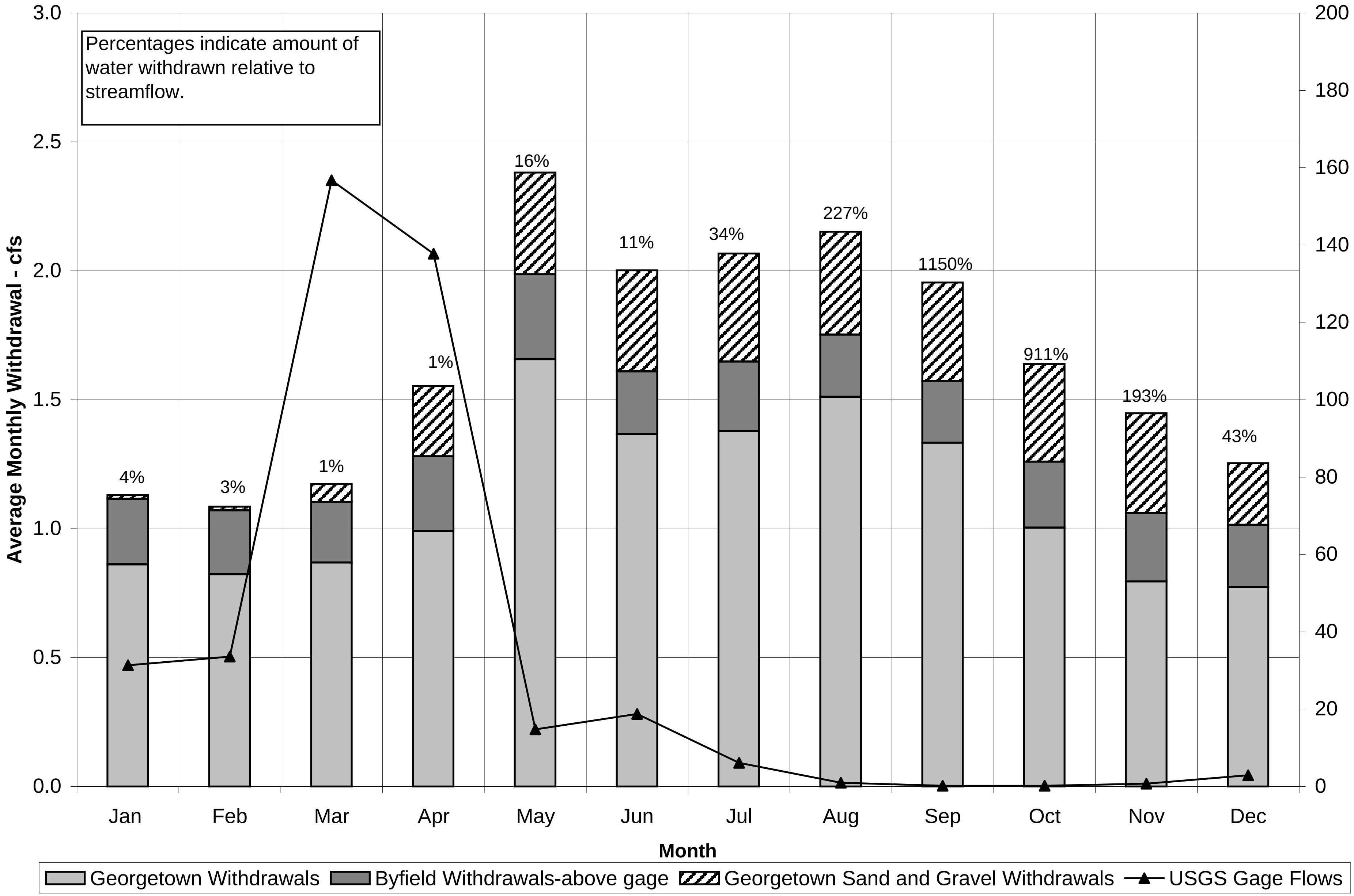


Figure 4.5-15: Comparison of Monthly Precipitation and Water Withdrawals made by Georgetown & Byfield Water Departments for the Period June, July, and August 1990-2001

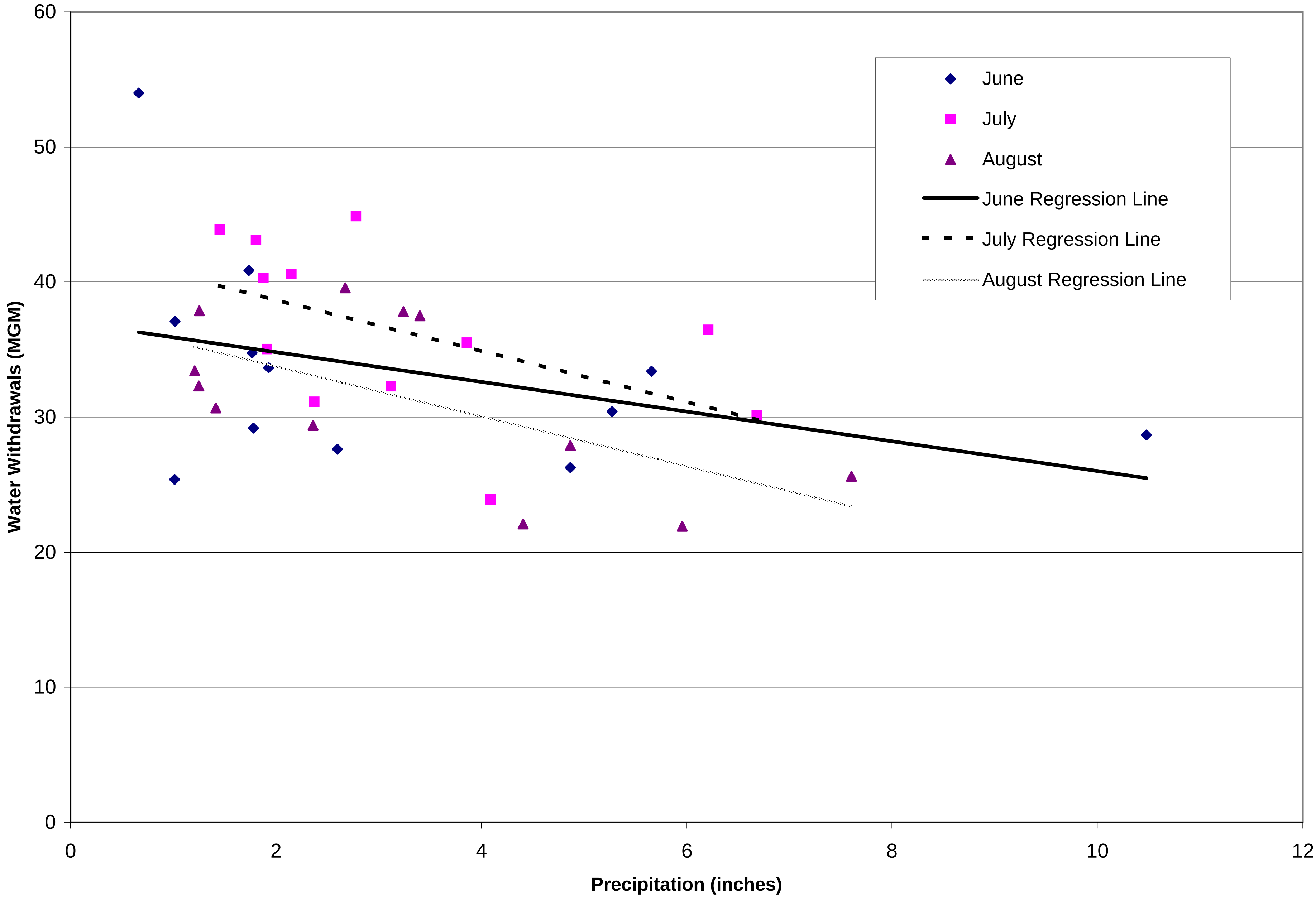
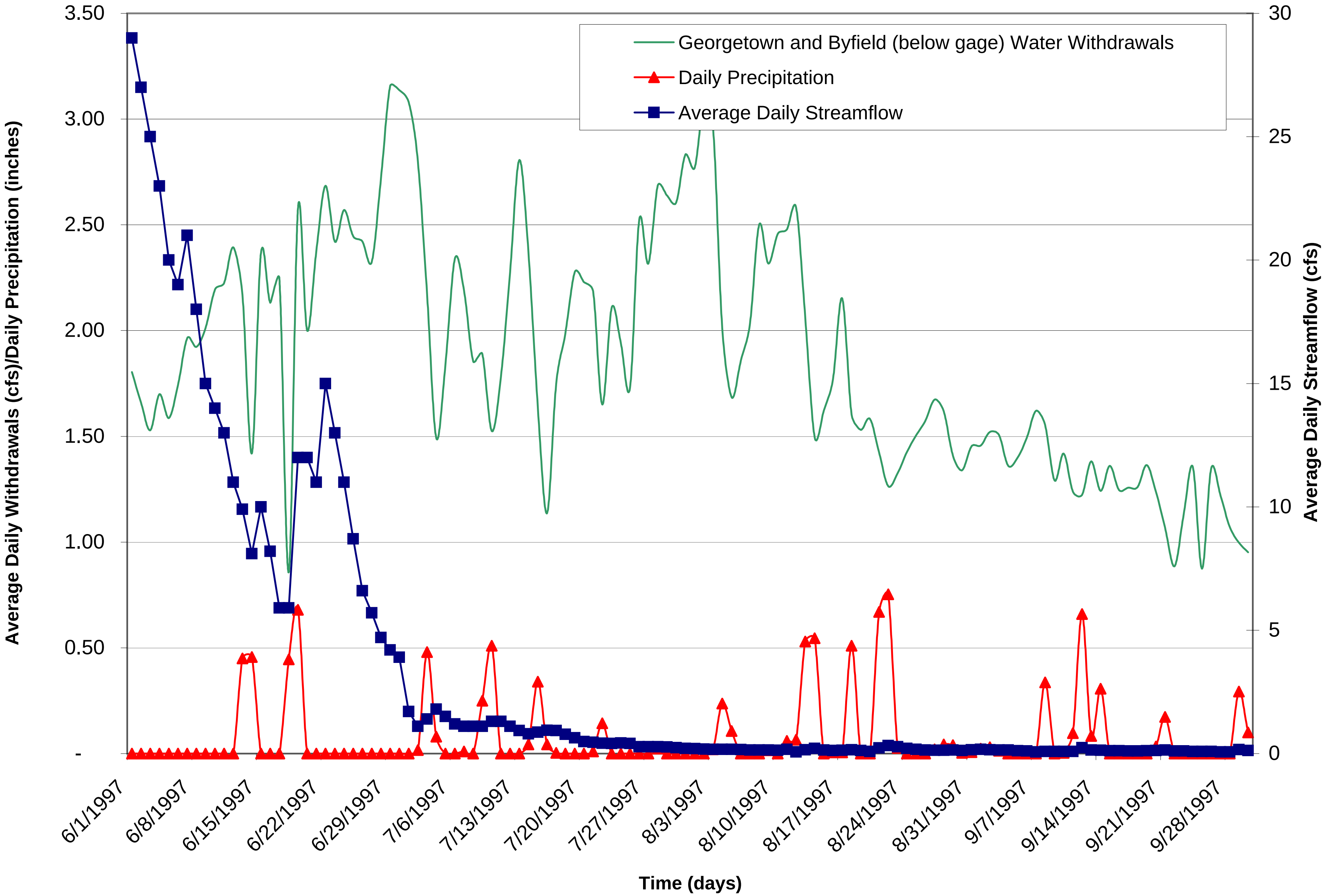


Figure 4.6-1: Average Daily Water Withdrawals for Georgetown and Byfield (Below Gage), Daily Precipitation, and Average Daily Streamflow at the Byfield USGS Gage for the Period June 1-September 30, 1997



5 Evaluation of Urban Development/Growth

5.1 Land Use Change

In general, urban and industrial development typically increases the amount of impervious or compacted surfaces such as roofs, roads, sidewalks, and parking lots. The result is cumulative changes in the streamflow dynamics of nearby rivers and streams. Since rainwater cannot penetrate such surfaces, it runs off, reaching the stream faster than it would naturally, increasing flood peaks and decreasing groundwater recharge and base flow.

Current and historic land use mapping was available from MassGIS for the years 1971, 1985, 1991, and 1999. Table 5.1-1 depicts the historic distribution of land use for the study area-the Parker River watershed above the Byfield USGS gage (21.3 square miles). Figure 5.1-1 shows the relative land use changes for the various category classifications using 1971 as the base year. Residential land use has increased 10.1% since 1971, while forest land has decreased 8.1%. Also, agricultural land use has decreased 2.4% since 1971.

Table 5.1-1: Land Use Distribution for the Parker River Watershed Above the Byfield USGS Gage (21.3 square miles)

Category	1971	1985	1991	1999
Cropland	6.2%	5.7%	5.1%	4.3%
Pasture	1.5%	1.8%	1.4%	1.1%
Forest	63.5%	59.4%	58.0%	55.4%
Wetland	6.8%	6.8%	6.8%	6.7%
Mining	0.9%	0.9%	0.7%	0.4%
Open Land	3.4%	3.0%	3.0%	2.8%
Recreation	0.4%	0.4%	0.4%	1.4%
Residential	13.6%	18.0%	19.8%	23.7%
Salt Wetland	0.0%	0.0%	0.0%	0.0%
Commercial	0.5%	0.5%	0.5%	0.6%
Industrial	0.1%	0.1%	0.1%	0.1%
Urban Open	0.5%	0.6%	1.3%	0.8%
Transportation	0.3%	0.3%	0.3%	0.3%
Waste Disposal	0.1%	0.1%	0.1%	0.1%
Water	1.6%	1.6%	1.6%	1.6%
Woody Perennial	0.6%	0.7%	0.8%	0.8%

5.2 Wetlands Changes

Wetlands play a critical role in regulating the movement of water within watersheds. Wetlands are characterized by water saturation in the root zone, at, or above the soil surface, for a certain amount of time during the year. This fluctuation of the water table above the soil surface is unique to each wetland type. In general, wetlands act to store precipitation and runoff and then slowly release the stored water into associated streams and rivers, groundwater aquifers, and the atmosphere via evaporative processes. Wetland types differ in their ability to manipulate water movement based on several characteristics, including: landscape position, soil saturation, vegetation density and type of vegetation.

In addition, wetlands help maintain the level of the groundwater table. The extent of groundwater recharge by wetlands is dependent upon soil, vegetation, site, and water table gradient. Groundwater recharge of up to 20% of wetland volume per season has been documented in some areas.

With regard to flooding flows, wetlands can act as natural sponges that store and slowly release flood waters. Trees, root mats, and other wetland vegetation also slow the velocity of flood waters and distribute them more slowly over the floodplain.

Relative to the Parker River watershed, wetlands were identified as a land use category in the previously discussed overall land use mapping scheme. Wetlands were defined as two types-nonforested freshwater wetlands and salt wetlands. Since 1971, the overall trend in wetland loss/gain has been very stagnant. As seen in Table 5.1-1, nonforested freshwater wetlands have decreased by only 0.1% for the Parker River watershed above the Byfield USGS gage between 1971 and 1999. There are no salt wetlands in this particular area of the watershed.

In addition, USGS topographic maps were obtained from the University of New Hampshire's Historic USGS Topographical Maps of New England and New York depository (UNH, 2002). Digital topographic maps dating back to 1952 and 1953 were obtained for the Parker River watershed above the Byfield USGS gage. These digital images were imported to a GIS and overlain with a digitized hydrography layer from MassGIS. The hydrography layer was developed from digitized hydrographic features from USGS 1:25,000 topographic quadrangles. These quadrangles were originally developed from aerial photography taken in 1978, and were subsequently edited and revised, as needed, in 1987.

Figure 5.2-1 illustrates the historic topographic maps along with the digital hydrography layer for the Parker River watershed above the Byfield USGS gage. Based on a qualitative analysis of the resulting map, there does not appear to have been any appreciable change in wetland area between the two maps sets. The three general areas denoted by the pink circles do not appear as wetland areas on the more recent digital hydrography layer. However, these areas were visually referenced to the topographic quad sheets for the area. These areas do not appear to have been filled or developed; rather it seems in the more recent mapping these locations were classified as upland.

It should be noted that this qualitative analysis of the topographic maps is somewhat limited by the resolution of the base mapping involved. Ideally to conduct this analysis, higher resolution maps would have been more desirable; however, this information was not readily available for the historic case. Therefore, a coarser analysis had to be relied upon.

Figure 5.1-1: Cumulative Change in Land Use for the Parker River Watershed Above the Byfield USGS Gage (21.3 square miles) Relative to 1971

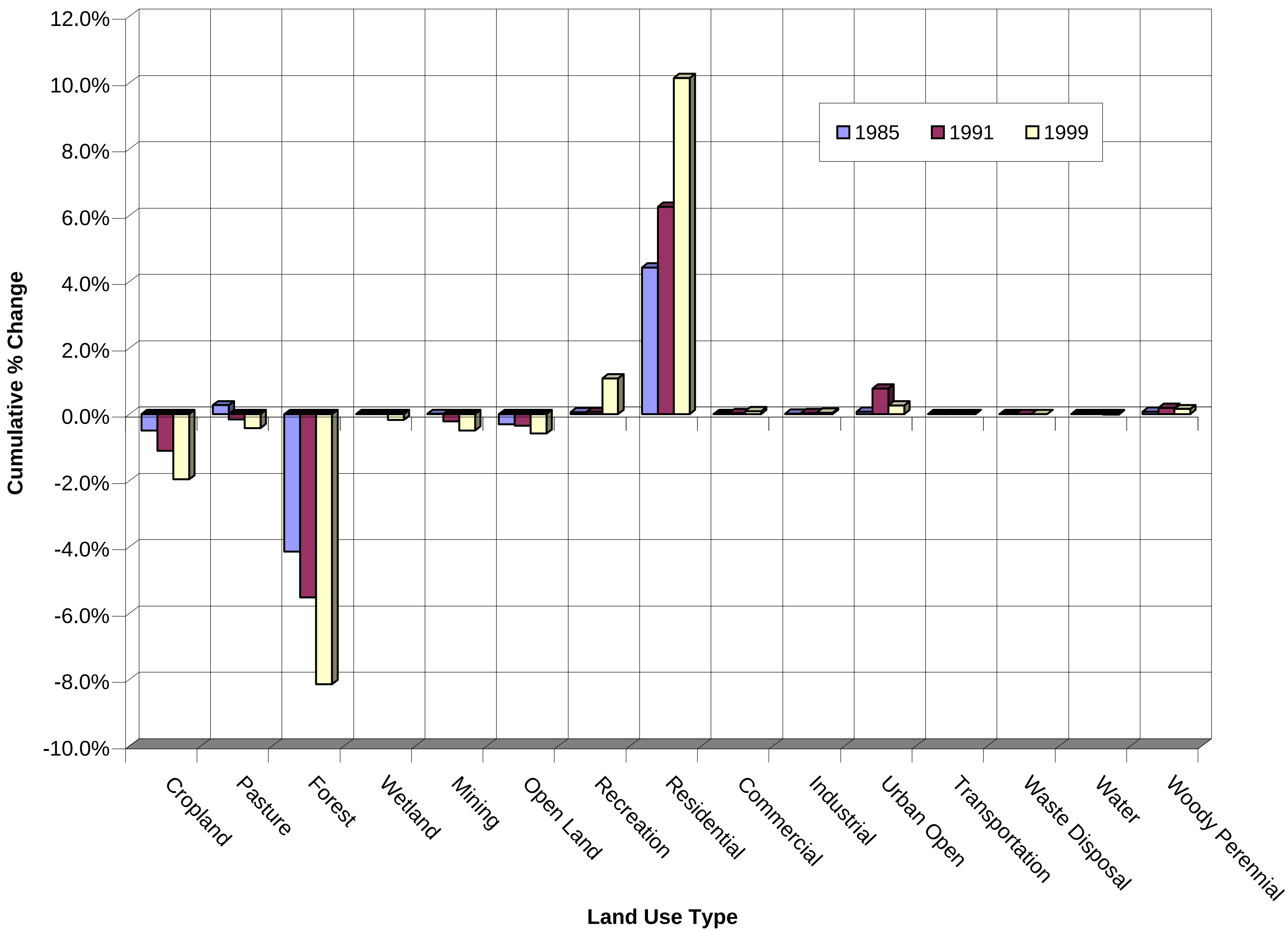
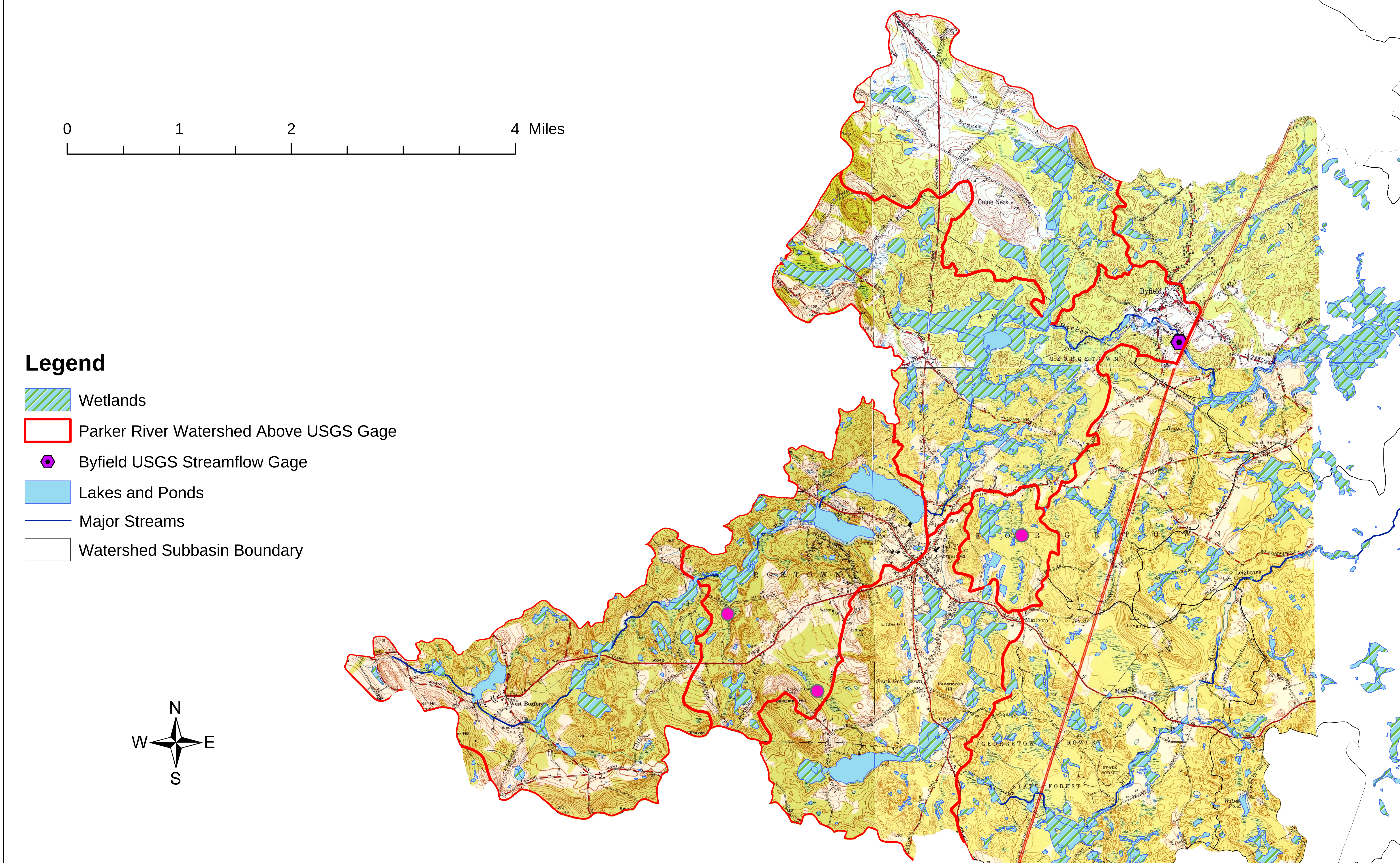


Figure 5.2-1: Historic Topographic Maps and Digital Hydrography Layer of Wetland Areas



6 Evaluation of Beaver Activity

A beaver flowage is an area along a stream or river periodically flooded by beaver. Beaver flowages are also called beaver ponds, beaver meadows, or mud flats, depending on the current level of beaver activity. Beaver activity is cyclic. Beavers move into a suitable area and flood it. Standing trees such as white pine are killed. Many aquatic plants quickly sprout in the open water. The combination of snags, open water, and aquatic plants provide habitat for wildlife. However, beaver/human conflicts have been increasing in recent years due to a growing and expanding beaver population. Because beavers have the ability to build dams to impound water, they can dramatically alter the environment in which they live. The problems beavers can cause fall into two main categories, tree cutting and flooding. In some cases, beaver activity can threaten property, agricultural crops or public health and safety. Beavers have potential to increase water-borne pathogens (including Giardia lamblia) downstream from their activity. Beaver dams also may negatively affect other natural resources. For example, dams can serve as barriers to migrating fish and cause inundation and siltation of rare plant and animal habitats.

6.1 Beaver Population Dynamics

For the period 1994 to 2001, beaver population estimates in the state of Massachusetts increased from 18,000 to 70,000. Historically, MDFW managed the beaver population by allowing a regulated harvest of beavers by licensed trappers. This increase in the beaver population is attributed to trapping restrictions imposed in 1996. Specifically, in 1996, the voters of Massachusetts passed a ballot referendum known as "Question One". This law prohibited or restricted (by permit only) many types of traps, such as conibear and other similar leg-hold traps. As a result, the annual harvest dropped from approximately 1,700 to less than 100 beavers. Consequently, the beaver population experienced exponential growth from 24,000 in 1996 to some 70,000 in 2001 (MDFW, 2002). In 2000 the Massachusetts Legislature modified “Question One” making it easier for people to obtain permits to solve public health or safety problems due to beaver flooding.

No existing information on beaver population dynamics was available specifically for the Parker River watershed. However, it is assumed that the statewide beaver population trends are also representative of the Parker River watershed. Coincident with the rising statewide beaver populations, the number of beaver/human conflicts has also increased. Figure 6.1-1 depicts the overall trend in statewide beaver population, as well as the number of beaver complaints filed within the Parker River watershed. Prior to July 2000, MDFW was responsible for administering beaver complaints; however, in subsequent years this responsibility has been undertaken by the local board of health within a particular community.

On December 13, 2002 and January 29, 2003, reconnaissance surveys were conducted to identify significant beaver dams and their general characteristics. The survey area focused on the mainstem of the Parker River, from its headwaters to the Byfield USGS gage, and was divided into 4 reaches as shown in the following graphic.

Reach # 1	Parker River from Glendale Road to Uptack Road
Reach # 2	Parker River from Uptack Road to Bailey Lane
Reach # 3	Parker River Downstream of Pentucket Pond to Thurlow Street
Reach # 4	Parker River from Thurlow Street to Byfield Gage

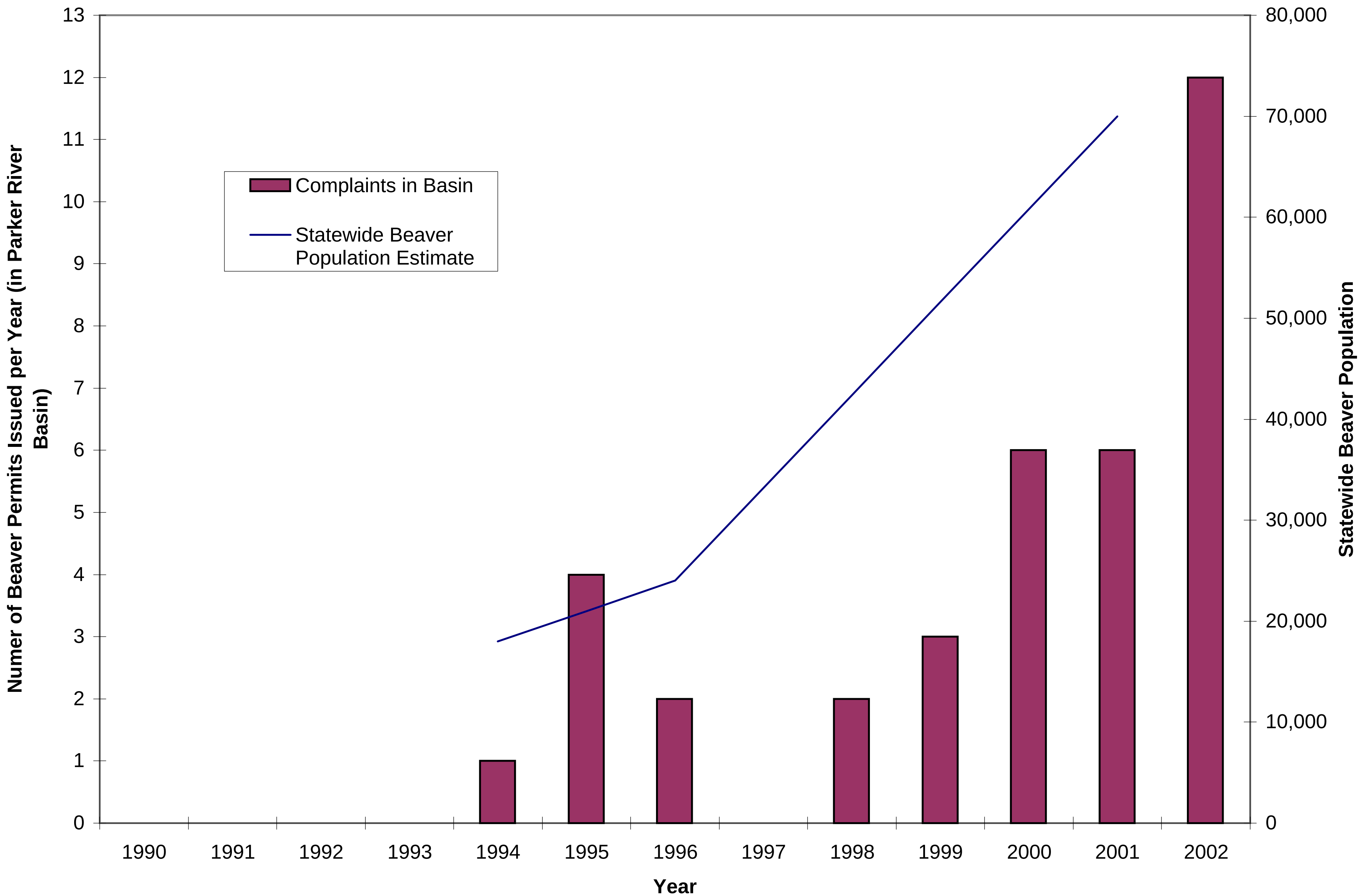
Specific information gathered included the location and dimensions of beaver dams, as well as a general estimate of the current beaver population within each flowage. The location of the beaver dams were acquired using a Global Positioning System (GPS) unit. Beaver dam dimensions were estimated during the reconnaissance. Beaver population estimates were made using standard protocols from the MDFW (C. Henner, personal communication).

Figure 3.6-1 (see Section 3) illustrates the location of each beaver dam identified during the reconnaissance surveys. In addition, Table 6.1-1 describes the general characteristics of each beaver dam. Site #'s 2, 5, 9, and 12 are the culvert openings at Route 133, Uptack Road, Bailey Lane, and Thurlow Street, respectively. In some instances, beavers have partially damned these openings to act as a water level control mechanism for flowages upstream of the sites, or in other cases the flow constriction created by the culvert acts to backwater upstream areas. The flowage upstream of Site #9 appeared to have no current beaver activity. A lodge was located in the flowage; however, no beaver sign were identified. It is assumed that the beaver colony in this area may have been eradicated to resolve a past complaint. Within Reach #3, an active beaver lodge was identified within the backwater formed by the Thurlow Street culvert. A local landowner was interviewed and reported previous beaver dam building activity in the area near the bridge, but no evidence was found during the survey. In addition, several beaver lodges were identified in Reach #4 near Crane Pond. However, it appeared that this area provided sufficient water depth for beaver; therefore, significant dam building was not necessary.

Table 6.1-1: General Characteristics of Beaver Dams along the Parker River Above the Byfield USGS Gage

Reach #	Site #	Dam Length (ft)	Dam Height (ft)	Population Estimate	Active Dam
1	1	10	1	6-8	Yes
	2 (Route 133 Culvert)	6	NA	6-8	Yes
	3	75	2	6-8	Yes
	4	65	1.5	2	Yes
	5 (Uptack Road Culvert)	8	NA	6-8	Yes
2	6	125	3	4	Yes
	7	175	4	6-8	Yes
	8	100	2	2	Yes
	9 (Bailey Lane Culvert)	8	NA	0	No
3	10	150	4	6-8	Yes
	11	40	1	2	Yes
	12 (Thurlow Street culvert)	NA	NA	4-6	NA
4	NA	NA	NA	12-16	NA

Figure 6.1-1: Statewide Beaver Population Estimates and Beaver Complaints Filed within the Parker River Watershed



7 Discussion and Conclusions

This study attempts to confirm the occurrence of unusually low flow events in the Parker River. Once confirmed, the study evaluates potential causes of these low flow conditions, and attempts to determine their relative magnitude of impact.

Occurrence of Low Flow Events

Previous studies, as well as actual field observations, have documented extreme low flow conditions in the Parker River during recent times. A statistical analysis, completed by MDEM, of streamflow data collected at the Byfield USGS gage, revealed a significant decline in the 7-day annual minimum flow statistic since 1993. In 1997, the PRCWA documented completely dry reaches of the Parker River below the Georgetown municipal water supply wells. Similar conditions have been documented in the Ipswich River watershed, which is located to the south of the Parker River watershed. Within the Ipswich River, several reaches exhibited interrupted or extremely low flows in 1993, 1995, and 1997. These conditions were mostly attributed to a series of water withdrawals along the mainstem of the river (USGS 2001).

The results of this study confirmed the previous statistical analysis and field observations that the occurrence of unusual low flow events in the Parker River has increased in recent times (WY 1990-2002). The IHA analysis of the Byfield USGS gage, which calculated key streamflow statistics for two separate periods (WY 1946-89 and WY 1990-2002), revealed significant and chronic decreases in the base flow, 1-day, 3-day, 7-day, 30-day, and 90-day annual minimum flow statistics for the period WY 1990-2002, when compared to the WY 1946-89 period. In addition, the IHA analysis indicated average monthly flows for June, July, August, and September were significantly lower during the WY 1990-2002 period as well.

In this geographic region, typically during the summer period (June-September) streamflows begin to naturally decrease with the onset of warmer and drier weather, as well as the growing season. The base flow, 1-day, 3-day, 7-day, 30-day, and 90-day annual minimum flow statistics are typically used to quantify the magnitude and duration of the resulting annual low flow conditions. For instance, during a given year, the 1-day annual minimum flow statistic represents the lowest single daily flow occurring during that year. The multi-day (3-day, 7-day, 30-day, and 90-day) annual minimum flow statistics represent the lowest multi-day average flow occurring during that year. For example, the 7-day annual minimum flow statistic would represent the lowest flow that occurred over 7 consecutive days during that particular year.

The median value of the base flow, 1-day, 3-day, 7-day, 30-day, and 90-day annual minimum flow statistics was computed for both the WY 1946-89 and WY 1990-2002 periods. When the median values for the two periods are compared, the results indicate that the Parker River experienced a significant decrease in the median value of the base flow, 1-day, 3-day, 7-day, 30-day, and 90-day annual minimum flows statistics of 86%, 85%, 85%, 86%, 81%, and 68%, respectively, during the WY 1990-2002 period. In addition, for the entire period of streamflow record at the Byfield USGS gage (WY 1946-2002), eight of the 10 lowest values of the 1-day, 3-day, 7-day, and 30-day annual minimum flow statistics occurred during the WY 1990-2002 period.

The median value of the average monthly flows for June, July, August, and September was also computed for both periods of the IHA analysis. The average monthly flow statistic is simply the average flow for a given month. The median value of the average monthly flows for June (40%), July (55%), August (80%), and September (22%) are significantly lower during the WY 1990-2002 period, when compared to WY

1946-1989. Also, when the entire period of flow record is considered for the month of July, the five lowest average monthly flow values ever recorded occurred during the WY 1990-2002 period. Similarly, for both August and September, four of the five lowest average monthly flow values ever recorded occurred during the WY 1990-2002 period as well.

To further analyze the flow regime of the Parker River, the USGS Streamstats program was used to estimate a completely unregulated/natural flow regime. For several low flow statistics, such as the 99%, 98%, 95%, 90%, 85%, 80% flow exceedances, as well as the 7Q2, 7Q10, and August median flows, the Streamstats program predicted higher flow values, compared to the same low flow statistics computed from actual flows measured at the Byfield USGS gage for the 1990-2002 period. The flow values measured during the historic period (WY 1946-89) at the Byfield USGS gage were generally within the range predicted by the Streamstats program.

Based on the previously discussed analyses, it is apparent that the occurrence of unusual low flow events within the Parker River has increased in recent times (WY 1990-2002), and is most likely caused by some activity or event within the watershed.

To determine the potential causes for the increase occurrence of low flow events, a series of hypotheses were developed and investigated. They included the following:

- Natural variations in the hydrologic cycle (i.e., reduced and/or changes in the timing precipitation);
- Increasing water withdrawals for public water supply and industrial uses;
- Increased urban development/growth within the study area; and
- Increased beaver activity within the study area.

The investigation of each hypothesis, which is contained in the preceding report sections, revealed that the cause of the unusual low flow events is due to a combination of influences. In order of relative significance, these influences include increasing water withdrawals for public water supply and industrial uses (especially summer peak use), development within the watershed, natural variations in the hydrologic cycle, and beaver activity along the Parker River.

Water Withdrawals

Rivers either gain water from inflow of groundwater (gaining stream) or lose water by outflow to groundwater (losing stream). Many rivers do both, gaining in some reaches and losing in other reaches. The flow directions (gaining or losing) between groundwater and surface water can change seasonally as groundwater levels change in response to the streamflow and precipitation levels. Under natural conditions, groundwater makes some contribution to streamflow, typically as a base flow component. Between precipitation events, rivers are primarily sustained by base flow.

A groundwater pumping well(s) can change the quantity and direction of flow between an aquifer and river in response to different rates of pumping. The adjustments to pumping of an actual hydrologic system may take place over many years, depending upon the physical characteristics of the aquifer, degree of hydraulic connection between the stream and aquifer, and locations and pumping rates of wells. Reductions of streamflow as a result of groundwater pumping are likely to be of greatest concern during periods of low flow as even a relatively small volume depleted from streamflow at that time can result in a relatively large adverse impact.

When groundwater pumping initially begins, all of the water supplied to a well originates from groundwater stored in the aquifer. If pumping rates exceed a critical threshold, the dominant source of water to a well, particularly wells that are completed in an unconfined aquifer, can change from groundwater storage to surface water (i.e., river, stream, wetland). The water pumped from a well can either decrease stream discharge or increase recharge from the stream to the groundwater system. The streamflow reduction in either case is referred to as streamflow capture. In the case of surface water withdrawals directly from a river, the loss in streamflow is obviously much more pronounced.

Increased water withdrawals for public water supply and industrial uses are the most significant factor affecting the occurrence of low flow events in the Parker River. Coincident with the period (WY 1990-2002) of decreasing flow in the Parker River, total water withdrawals in the study area have increased dramatically. Although the entire study area returns wastewater to the watershed via septic systems, increased summer water use and evaporative losses from irrigation and plant transpiration effectively remove water from the local hydrologic system and it is not returned to the river.

Overall, GWD's water withdrawals seem to have the greatest impact on Parker River streamflows. This is based on the overall magnitude of its withdrawals relative to other users, and the significant rate of increase in its withdrawals over time. GWD's annual withdrawal volume has risen consistently, ranging from 177 MGY (0.49 MGD) in 1990 to 263 MGY (0.72 MGD) in 2001. GWD's peak day to average daily withdrawal ratio has been above 2.2 for the 1997-2001 period.

In terms of withdrawal volume, GSG's withdrawals appear to have less impact on streamflows, relative to GWD. GSG's total annual withdrawals have been reportedly decreasing in recent years; however, the cause of this decrease is unknown. The fact that GSG withdraws water directly from the Parker River, as opposed to pumping from a well, likely has a more direct adverse impact on streamflow. GSG's annual withdrawal volume has reportedly ranged from 189.9 MGY (0.52 MGD) in 1997 to 65.5 MGY (0.18 MGD) in 2001. GSG is reportedly discontinuing their operation in the near future.

Relative to GWD and GSG, water withdrawals by BWD likely impact streamflow the least. The overall magnitude of water withdrawals made by BWD is less than the other two water users. In 1998, BWD installed a deep bedrock well near Forest Street to serve as its primary water source. It is likely that this well has a lesser degree of hydraulic connectivity to the river compared to GWD's shallow gravel wells, and certainly less of a direct impact compared to GSG's surface water withdrawal. However, BWD still occasionally makes secondary water withdrawals from its Larkin Road well, which was previously discovered to have a high degree of hydraulic connectivity to the Parker River. It is not known whether these reduced water withdrawals still significantly impact streamflow. Since the Larkin Road well acts to supplement water supply during peak periods, these withdrawals typically occur during the summer period when streamflows are at their lowest. BWD's peak day to average daily withdrawal ratio dropped noticeably in 2000 (1.55) and 2001 (1.88). It is possible that water conservations measures may be partly responsible for this decline. BWD's annual withdrawal volume from all sources has ranged from 57.0 MGY (0.16 MGD) in 1994 to 79.3 MGY (0.22 MGD) in 1999. Withdrawals from the new Forest Street well alone ranged from 69.7 MGY (0.19 MGD) in 1999 to 61.2 MGY (0.17 MGD) in 2001.

Water demand in the study area continues to increase from new users as well. GCC's water use (beginning in 1997) is relatively low compared to the other three major users; however, most of this water is used for irrigation during the summer season, which likely results in high evapotranspiration rates and very little of the withdrawn water being returned to the watershed. GCC's annual withdrawal volume has reportedly ranged from approximately 15.5 MGY (0.06 MGD) for the 1997-1999 period to 12.9 MGY (0.05 MGD) in 2002, and is concentrated over the summer months.

There are several other below-thresholds users in the study area; however, their overall impact is expected to be small relative to the major users. Additionally, most of this water is returned to the watershed via to septic systems.

In addition, the rising population of the study area is expected to further increase the need for future water withdrawals. In the case of Georgetown, historic data suggest that the additional demand for water is expected to increase at a higher rate compared to population. For instance, daily water use in Georgetown increased steadily from 0.49 MGD in 1990 to 0.72 MGD in 2001, an increase of 48%. The population of Georgetown grew 16% from 1990 (6,384) to 2001 (7,421). It is suspected that this increased water demand is a result of non-household uses such outdoor watering, etc. In the case of Byfield, daily water use increased from 0.17 MGD in 1990 to 0.20 MGD in 2001, an increase of 14%. The service population of Byfield grew 12% from 1990 (1,800) to 2000 (2,015). This analysis of population and water use trends was hindered by inconsistencies in the methods used by water users to report their population served. Other sources of population data were used to estimate these trends.

Further exacerbating the problem of increasing annual water withdrawals in the study area is the seasonal increase in water demand that typically occurs during the summer period. In the cases of GWD and BWD, it appears that outdoor water use is primarily responsible for the increased summer water demand. On average for the period 1990-2001, GWD's monthly water usage varies significantly ranging from a low of 13.3 MG in February to 29.0 MG in July. BWD's average monthly water usage varies ranging from a low of 4.35 MG in February to 7.42 MG in July. GSG's monthly water usage is lowest in February at 3.6 MG, but remains consistently higher through the summer and fall with a high in June of 14.0 MG, and is a direct result of the seasonal nature of their business. In 2002, GCC's monthly water usage varied from 0.48 MG (April) to 3.21 MG (July). The peak day withdrawal to average daily withdrawal ratio for GWD and BWD is 2.36 and 2.28, respectively. Generally, ratios above 1.5 are considered excessive, and an indication that the water demand is in need of more effective management.

This increase in water demand typically occurs when streamflows are already at their lowest levels for a given year. Monthly water withdrawals in the study area were compared to monthly flow measured at the Byfield USGS gage for the period 1990-2001. During the months of July, August, and September, total water withdrawals in the study area were 31%, 40%, and 25%, respectively, of the average monthly flow measured at the Byfield USGS gage (see Figure 4.5-2). This condition worsens during particularly dry years. For instance, in 1995 GWD's total water withdrawals alone were 307%, 1,150%, 1,052% greater than the average monthly flow measured at the Byfield USGS gage for the months of July, August, and September, respectively (see Figure 4.5-8). In 1997, during the months of July, August, and September, GWD's and GSG's water withdrawals in the study area were 309%, 1,526%, and 1,641% greater, respectively, than the average monthly flow measured at the Byfield USGS gage (see Figure 4.5-10). In 2001, this situation even carried over into the months of October and November when total water withdrawals from all three major users exceeded average monthly streamflow by 911% and 193%, respectively (see Figure 4.5-14).

Total precipitation appears to be a key variable, when considering the aforementioned interplay between water withdrawals and available streamflow. Obviously, the amount of precipitation a given watershed receives directly affects the level of streamflow. In addition, municipal water supply demands within the study area, and in turn the magnitude of water withdrawals, are strongly driven by total precipitation. For instance, during July 1997 GWD and BWD withdrawals were 34.29 MG and 8.83 MG, respectively, while total precipitation was 1.81 inches. In contrast, the GWD and BWD withdrawals in July 1996 were 24.11 MG and 6.03 MG, respectively, while total precipitation was 6.68 inches. During these two time periods, withdrawals from GSG were identical (17.1 MGM). In addition, a regression analysis of total water withdrawals and precipitation for the months of June, July, and August during the period 1990-2001, showed a trend of increasing water withdrawals with decreasing precipitation. Users are obviously curtailing outdoor water use during rainy periods.

Urban Development/Growth

Development, resulting in changes to land use and wetland loss, within the study area seems to have moderately impacted Parker River streamflows. Specifically, increases in the amount of impervious surfaces such as roofs, roads, sidewalks, and parking lots have resulted in changes to streamflow dynamics in the study area. Since precipitation cannot infiltrate these surfaces, it runs off, reaching nearby streams faster compared to natural conditions; thus, increasing flood peaks and decreasing groundwater recharge and in turn base flow[6].

A land use trend analysis completed for the study area revealed a 10.1% increase in residential land use since 1971. This increases impervious surfaces, reduces infiltration and increases water demand (both household use and lawn irrigation). In a coincident timeframe, forest and agricultural land decreased 8.1% and 2.4%, respectively. The overall trend in wetland loss appears to have been very stagnant. Based on land use mapping information, nonforested freshwater wetlands have decreased by only 0.1% within the study area. In addition, qualitative comparisons between historic (circa 1952) and recent (1987) topographic maps also indicate very little appreciable change in wetland area. Overall, the wetlands loss analysis was very coarse in nature, and would likely identify only large losses in wetlands acreage.

The resulting increases in impervious area from residential development have increased flood peaks in the watershed over time, as well as contributed to decreases in base flow. This is evidenced by the results of the long term (WY 1946-2002) IHA analysis of the Byfield USGS gage, which indicated that the 1-day, 3-day, 7-day annual maximum flow statistics (see Figures A-19 through A-21) showed a significant increase in magnitude over time. These flow statistics are indicators of annual extreme high water conditions. In addition, the streamflow rise and fall rates (see Figures A-30 and A-31), which are indicators of how quickly runoff reaches nearby streams, exhibit increasing trends over time as well. The long-term (WY 1946-2002) IHA analysis of the base flow, 1-day, 3-day, and 7-day annual minimum flow statistics exhibit moderately decreasing trends over time, indicating that base flows have been reduced.

Precipitation Patterns

Natural variations in the hydrologic cycle (i.e., precipitation patterns) have had a marginal impact on the occurrence of unusual low flow conditions in the Parker River. Obviously, precipitation is the main factor dictating streamflow levels in a watershed, and the Parker River watershed has been subjected to several periods of decreased precipitation in recent times (WY 1990-2002). These drought periods have contributed to below normal streamflow levels; however, the lack of precipitation alone is not sufficient to explain the significant and chronic occurrence of low flow events in the Parker River.

A comparison of annual average precipitation for the period WY 1946-89 and WY 1990-2002, actually revealed that the WY 1990-2002 period received on average approximately 2 more inches (4.3% higher) of precipitation per year. Based on these calculations, it would be expected that streamflow would be higher for the recent period; however, when average annual streamflow for the period is computed, both periods exhibit essentially the same volume of runoff. In addition, previous analyses within this report (IHA and Streamstats analyses) have described the decrease in streamflow exhibited during the WY 1990-2002 period. This would indicate that there has been a consumptive loss within the water budget for the study area. It is likely that increased evapotranspiration from increased irrigation (i.e., lawn watering, etc.) is partly attributable to this water loss.

Further evidence suggests that precipitation pattern variations are not solely responsible for the increased occurrence of low flow conditions in the watershed. Over the entire period of precipitation record, the

[6] Base flow is the sustained low flow in a stream; groundwater discharge is the source of base flow in most places.

study area has experience varying degrees and length of drought. A comparison of historic dry periods (WY's 1957, 1965, and 1966) with recent dry periods (WY's 1995, 1997, and 2002) showed that even though the historic dry years had lower precipitation levels relative to the dry years in the recent period, the 7-day annual minimum flows were higher during the historic years. In particular during the dry year of 1957, the June-September precipitation totaled 5.4 inches, approximately 3.3 inches less that what occurred during the same period for the years 1995 and 1997. In spite of this, the 7-day annual minimum flow for 1957 was approximately equal to or greater than what occurred during both 1995 and 1997. The same general trends were evident when comparing the August median flows for each year. Thus, our recent droughts have been less severe, yet the river is being more severely depleted.

Beaver Activity

Beaver activity along the mainstem of the Parker River seems to have a relatively minor impact on streamflow conditions. The mainstem of the Parker River currently has a very healthy beaver population with numerous dams located along the river's entire length. Beaver dam impoundments can have both beneficial and detrimental effects on stream hydrology. Beaver dam impoundments increase the amount of water stored in a river system, similar to how a wetland complex or meadow would retain water. The water surface area created by an impoundment can result in increased evaporation rates, particularly during the summer. The impoundment can also be beneficial to water supply, by acting to recharge groundwater levels in adjoining aquifers, by slowing the flow rate and allowing increased infiltration to depleted aquifers.

Most of the beaver impoundments along the Parker River are not large enough to significantly decrease streamflow via evaporative processes. Several beaver impoundments located in the headwaters of the Parker River are quite small, and situated in areas that were previously wetland or meadows, and were likely previously flooded for a portion of the year. The impoundment located within the GWD well complex is quite large in size; however, topographic maps suggest this impoundment was in place prior to the WY 1990-2002 period of decreased streamflows. It is also quite likely that this impoundment serves a beneficial purpose to water supply by enhancing recharge into the aquifer that serves the well complex.

Results of the streamflow measurement analysis are most indicative of the relatively minor impacts of beaver activity on streamflow. The stream reach between Glendale Road and Uptack Road immediately upstream of the GWD well complex contained several beaver dams. However, streamflow actually increased between the upper and lower endpoints of this reach. This is contrasted with the stream reach that contained the GWD well complex. This stream reach has three beaver dams situated near the well complex. In this case, there was a significant decline in streamflow between the upper and lower endpoints of this reach. Based on these results, the operation of the GWD well field has a greater impact on streamflow, relative to the presence of beaver dams.

8 Recommendations

Based on the study conclusions, several recommendations are proposed to better manage the water resources of the Parker River watershed, as well as address key impacts identified by the various analyses. The recommendations are divided into three categories; general, short-term, and long-term.

8.1 General Recommendations

General recommendations were developed to address issues that were encountered during the study process. In some cases, these issues hampered the analyses conducted within the study. These recommendations are made in an effort to avoid similar issues during future studies of this kind.

- The Public Water Supply Annual Statistical and Registered & Permitted Withdrawals Annual Reports are valuable data sources for examining historic and present water use, as well as projecting future water use within the Commonwealth. This system relies on self-reporting by water users. The WMA requires five-year reviews for each withdrawal permit, in which compliance with various regulations is evaluated. However, it appears that in many cases, the data provided by water users goes unverified. Users are required to meter water withdrawals and meter calibration is required on a regular basis. Therefore, actual withdrawal volumes reported are most likely accurate in the majority of cases. However, the accuracy of metering by some non-public water suppliers (GSG and G-Town Produce) evaluated in this study is questionable. Other information provided on the reports appears to be less accurate. For instance, data on the population served by each public water supplier appeared to be estimates. In several cases, the method for making the estimates changed over time, and in other cases the same values were repeated for several years. This complicated the process of evaluating historic water use trends with population growth. Accurate calculation of water suppliers' gallons per capita day use was hampered as well by this reporting inconsistency. This statistic is important in assessing proper water demand management practices. In addition, the state has set the 70-80 gallons per capita day use threshold as a trigger to further investigate consumptive use and determine if conservation efforts are needed. It is recommended that MDEP improve efforts to verify the accuracy of all future data reported as part of this regulatory program. Beyond reporting accuracy issues, MDEP should consider effects of streamflow depletion being caused by the water withdrawals in its review and renewal of WMA permits.

8.2 Short Term Recommendations

Short term recommendations were developed to address the impacts identified within this study. These recommendations are relatively modest and could be implemented within one year or sooner of the study publication date. Also, these recommendations are considered to be relatively inexpensive to implement, but could potentially have far-reaching benefits in alleviating the low flow conditions experienced in the Parker River.

The results of this study indicated that increased water withdrawals, particularly by GWD, for public water supply and industrial uses were the most significant factor affecting the occurrence of low flow events in the Parker River. Of particular concern was the problem of the seasonal increase in water demand that typically occurs during the summer period. Evidence shows that outdoor water use is primarily responsible for the increased summer water demand. It is recommended that the initial steps to mitigate the low flow problem in the Parker River focus on decreasing peak summer water demand, so that existing water supplies are sufficient to serve needs, while reducing environmental impacts to water resources. The short term recommendations fall into two subcategories; immediate measures to better manage water use and demand during particularly sensitive periods and approaches to gain more data to better quantify the cause of the problem.

- Both GWD and BWD have mandated outdoor watering restrictions in recent years during dry periods. It is recommended that GWD and BWD take additional measures to enforce compliance with the existing restrictions, as well as increase public outreach to educate end-users of the need for water conservation during these critical periods. If there is a high rate of compliance, then more stringent water restrictions are warranted during dry periods to decrease water demand. For example, the odd-even watering restrictions that are currently implemented may have little impact if automated sprinkler systems are operating at every opportunity. Allowing outdoor water use only one or two days a week and/or during limited hours may be much more effective. In some areas of the country, water users are asked to follow an every-third-day (at most) watering schedule for lawns, and water only between 8 p.m. and 8 a.m. to reduce water lost to evaporation. BWD's peak day to average daily withdrawal ratio dropped noticeably in 2000 (1.55) and 2001 (1.88). It is possible that more effective water conservations measures are responsible for this decline.

- Both GWD and BWD have peak day to average daily withdrawal ratios exceeding 2.0 for the period 1990-2001, which is considered excessive. Through aggressive water conservation measures and public outreach, GWD and BWD should limit this ratio to 1.5, as well as cap gallons per capita day use to 65. In addition, both GWD and BWD should take measures to limit unaccounted for water to 10% or less if possible. The water conservation measures should be aggressive in nature, as a substantial drop in water use will be necessary to achieve these limits. MDEP should incorporate these new, more stringent, limits into the next 5-year water withdrawal permit for each water supplier.

- BWD historically used the Larkin Road well to supplement their Forest Street well withdrawals during peak periods. The Larkin Road well was previously discovered to have a high degree of hydraulic connectivity to the Parker River. BWD should evaluate this management practice to ensure it is the most effective method of providing water. It may be beneficial to increase the pumping rate at the Forest Street well, which presumably has a lesser degree of hydraulic connectivity to the river, rather than rely on Larkin Road well to meet peak demand.

- The fact that GSG withdraws water directly from the Parker River, as opposed to pumping from a well, likely has a more direct adverse impact on streamflow. If GSG continues their operation, it is recommended that they investigate the possibility of establishing an on-site water source, such as a well, to replace the surface water withdrawal, which would have less direct impacts on streamflow.

- GCC began withdrawing water for irrigation purposes in 1997. Based on the research conducted during this study, it does not appear that GCC has been required to report their water use. The need for GCC to obtain a permit and report their withdrawals under the provisions of the WMA should be evaluated by MDEP. According to GCC, approximately 37 acres of the golf course facilities are irrigated. The MDEP Golf Course Water Use Policy presumes that courses irrigating 35 acres or more categorically exceed the WMA permit threshold of 9 MG during the peak 3 month irrigation period. Management practices to reduce the amount of acreage irrigated should be evaluated and implemented, as the majority of water typically used for irrigation is lost via evapotranspiration processes.

- Development, resulting in changes to land use, within the study area was found to have moderately impacted Parker River streamflows. Zoning changes or bylaw creation to assist communities in reducing future water use is imperative. It is recommended that local planning boards carefully scrutinize new applications for large-scale development (i.e., large subdivisions, golf courses, etc.).

Planning Boards may wish to consider implementing a water bank or otherwise mandate mitigation measures to off-set the impacts of future developments to assure these do not place further demands on the water systems and exacerbate low-flow conditions on the Parker River. Other techniques for reducing environmental impacts of development are to prevent removal of topsoil from sites, limit the area disturbed on building sites, limit the area of lawn that is allowed on lots, and promotion of alternative lawn and landscape designs. These steps reduce the amount of water used in landscape establishment and maintenance. Some towns are also considering a ban on automated sprinkler systems or mandating water sensors that prevent the sprinkler system from activating when it is raining. Studies show that homes with automatic sprinklers use up to 30% more outside water than homes with manual systems. Also, installation of drip irrigation systems for non-turf areas can increase water use efficiency up to 75%.

- Rivers either gain water from inflow of groundwater (gaining stream) or lose water by outflow to groundwater (losing stream). Many rivers do both, gaining in some reaches and losing in other reaches. The flow directions (gaining or losing) between groundwater and surface water can change seasonally as groundwater levels change in response to the streamflow and precipitation levels, as well as groundwater pumping rates. It is likely that the reach encompassing the GWD well field has a high degree of hydraulic connectivity to the river and is both a gaining and losing stream under various hydrologic conditions. It is recommended that two gages be installed at the endpoints of this reach to continuously monitor streamflow levels. Additionally, groundwater levels in the reach should be monitored, either by the existing wells or by newly installed monitoring wells. These data, in conjunction with precipitation information, would be useful to help understand the timing and magnitude of the gaining/losing stream dynamic. It would also be useful to document if the water table is being gradually lowered at the river as a result of increasing groundwater withdrawals. This understanding could be used to better manage (limit) pumping rates during critical periods based on streamflow and groundwater conditions.

- It is recommended that the public water suppliers develop drought management plans, which incorporate current aspects of their water conservation strategy as well as the recommendations described above. The primary objective of a plan would be to assist communities in managing water used for lawn and landscape maintenance during dry periods or water shortages. The plans should consist of a series of "drought indicators" such as precipitation, groundwater, and/or streamflow levels that can be used to assess the severity of a dry period. In response to a particular drought severity level, appropriate water use restrictions should be developed. Water restrictions should be enforceable restrictions that are implemented through the municipality's water use restriction by-law or by the regulations of a water district. The by-law should provide for a graduated system of increasingly stringent restrictions, culminating in a ban on outdoor water use, so that a water supplier can implement an appropriate response based on the severity of dry conditions or water supply problems. Communities that have insufficient water supplies may implement parts of their plan during non-drought years to help reduce peak demands that threaten the water supply system or the environment.

8.3 Long Term Recommendations

Several long term recommendations were also developed to address the impacts identified within this study. These recommendations are broader and more aggressive in scope, and would require more time and funding resources than the short term recommendations. The long term recommendations fall into two subcategories, measures for further study of the issue and approaches to more efficiently manage the water supply system.

- It is recommended that a safe yield analysis, relative to groundwater supply withdrawals, be conducted within the study area, as well as the remainder of the Parker River watershed. Safe-yield is the total quantity of groundwater that can be artificially withdrawn from an aquifer for water supply; and which naturally discharges to a stream without exceeding the aquifer recharge value for the area of consideration. Identifying and maintaining safe yield withdrawals will prevent long term and short term aquifer depletion, and in turn prevent streamflow capture (i.e., excessive loss of streamflow from groundwater pumping). An additional component of the safe-yield analysis should include an instream flow study, which will assist in determining appropriate minimum streamflow levels necessary to sustain aquatic habitat in various sections of the river.

- This study was focused on the watershed area upstream of the Byfield USGS gage. The main relevance of selecting the Byfield USGS gage as the downstream limit of the study area was that the data generated from it helped to identify the occurrence of the unusual low flow conditions. There are several other significant streams located within the watershed that could be similarly impacted by water withdrawals. These include the remaining freshwater portion of the Parker River, the Mill River, and the Egypt River. These streams are not equipped with flow monitoring devices, so there is no way to confirm and quantify the magnitude of the suspected problem. It is recommended that flow monitoring be instituted on these streams. Additionally, if streamflow depletion is identified, then studies should be completed to identify the causes and offer remedies to the problem.

- The results of this study indicated that increased water withdrawals for public water supply and industrial uses were the most significant factor affecting low flow conditions in the Parker River. Of particular concern was the problem of the seasonal increase in water demand that typically occurs during the summer period. Neither GWD, BWD, nor GSG have significant water storage capabilities that could be utilized during the peak demand periods to curb water withdrawals during periods of low flow. It is recommended that water storage options on a micro and macro scale be investigated. On a macro scale, water storage reservoirs would ideally limit the need to increase summer withdrawals and thus lessen the impact on streamflow. Creation of new reservoirs would allow storage of excess spring runoff, and allow for augmentation of summer demand by drafting water from storage. Previous studies (Metcalf and Eddy 1973) have identified potential sites for surface water reservoirs. The pros and cons of developing these water storage reservoirs would also have to be carefully evaluated in terms of regulatory hurdles, permitting process, hydrologic evaluations, environmental impact analysis, economics, and the political landscape. On a slightly smaller scale, both GWD and BWD have water storage tanks; however, their capacity is only sufficient to supply water for a short period of time. Both water suppliers, as well as, GSG should explore options to develop more substantive storage of this type. On a micro scale, developing small storage tanks for subdivisions to provide non-potable, outdoor water supply to offset summer demands should be investigated. Residential homeowners should be encouraged to utilize cisterns and rain barrels to collect and store rainwater for outdoor use. (1,000 square feet of roof can collect 420 gallons of water from 1 inch of rain. The water collected in a cistern, can be siphoned off to water gardens or wash cars).

- It is recommended that GWD, GSG, and BWD investigate the possibility of importing water to the study area for use during critical periods. Imported water would reduce the reliance on water withdrawals from/near the Parker River. The Ipswich River watershed has experienced problems with excessive water use, and would not be a candidate for providing water. However, other neighboring watersheds with storage capacity could be possibilities to provide supplemental water during critical periods. Any plan to import water would need to be consistent with the Massachusetts Interbasin Transfer Act, which has jurisdiction over transferring water outside of town and watershed boundaries via water supply and wastewater disposal.

- It is recommended that GWD, GSG, and BWD, as well as other major water users in the entire Parker River watershed develop a long-term regional public water supply plan to meet current and projected water needs (as opposed to demands). The water supply plan should incorporate facets of the previous recommendations (i.e., water conservation measures, drought management, safe yield analysis, potential for water storage). Additionally, the findings of this study indicated that the Parker River suffers somewhat from the uncoordinated management of several relatively small water users/providers. The water resources of the Parker River watershed may benefit from more consolidated management of this resource. A regional water authority or board comprised of representatives from all water users/providers in the watershed should be formed, with the mandate of implementing the aforementioned water supply plan and regionalizing service. If done properly, it is likely that regionalization would add more flexibility to meet water needs, and also benefit environmental resources. As the results of this study have indicated, water withdrawal locations in the watershed have differing levels of impact; some have more impact, other less, or no impact. Having the ability to shift pumping locations, times, and rates from areas of high impact to low impact at crucial times would benefit the sustainability of the Parker River waters resources.

9 References

Byfield Water District. Personal Communication with Paul Colby, Water Superintendent, 2002.

Gomez and Sullivan, Saugus River Water Budget and Instream Flow Study, Final Report, June 2002.

Metcalf & Eddy, Public Water Supply Resources of the Parker River Basin, May 29, 1973.

Richter, Brian, Baumgartner, Jeffrey, Powell, Jennifer, and Braun, David, A Method for Assessing Hydrologic Alteration within Ecosystems, The Nature Conservancy, Conservation Biology, Page 1163-1171, Volume 10, No. 1, August 1996.

The Executive Office of Environmental Affairs (EOEA), Parker River Watershed Homepage, Obtained from website: http://www.state.ma.us/envir/mwi/parker.htm, 2001.

Ipswich River Watershed Association, Ipswich River Photo Album, Obtained from website http://www.ipswichriver.org/IpswichRiverPhotoAlbum.pdf, 2003.

Massachusetts Department of Environmental Management (MDEM), Request for Response, Parker River Low Flow Study, 2001.

Massachusetts Department of Environmental Management (MDEM), Personal Communication with Steve Asen, 2003.

Massachusetts Department of Environmental Protection (MDEP), Parker River Watershed Water Quality Assessment Report, August 2001.

Massachusetts Department of Fisheries and Wildlife (MDFW). Personal Communication with Chrissie Henner, Wildlife Biologist. Beaver complaint data provided by e-mail, 2002.

Massachusetts Watershed Initiative (MWI), Parker River Watershed Team, Parker River Watershed Year 3 Watershed Assessment Report, June 2002

Parker River Clean Water Association (PRCWA), Parker River Stops Flowing in Georgetown, MA, Obtained from website: http://www.parker-river.org/flow/noflow1997.htm, 2001.

United States Geological Survey (USGS), Ries, Kernell G. and Friesz, Paul J., Methods for Estimating Low-Flow Statistics for Massachusetts Streams, Water-Resources Investigation Report 00-4135, 2000.

United States Geological Survey (USGS), Armstrong, David S., Richards, Todd A., and Parker, Gene W., Assessment of Habitat, Fish Communities, and Streamflow Requirements for Habitat Protection, Ipswich River, Massachusetts, 1998-99, Water-Resources Investigation Report 01-4161, 2001.

United States Geological Survey (USGS), Water Resources Homepage, Obtained from website: http://waterdata.usgs.gov/ma/nwis/uv?01101000, 2002.

University of New Hampshire (UNH), Dimond Library Documents Department & Data Center, Historic USGS Maps of New England & New York, Obtained from website: http://docs.unh.edu/nhtopos/, 2002.

Appendix A- Graphs from the Evaluation of Long Term Hydrologic Trends at the Byfield USGS Gage (IHA Analysis)

Figure A-1: Parker River USGS Gage at Byfield Average Monthly Flow for January

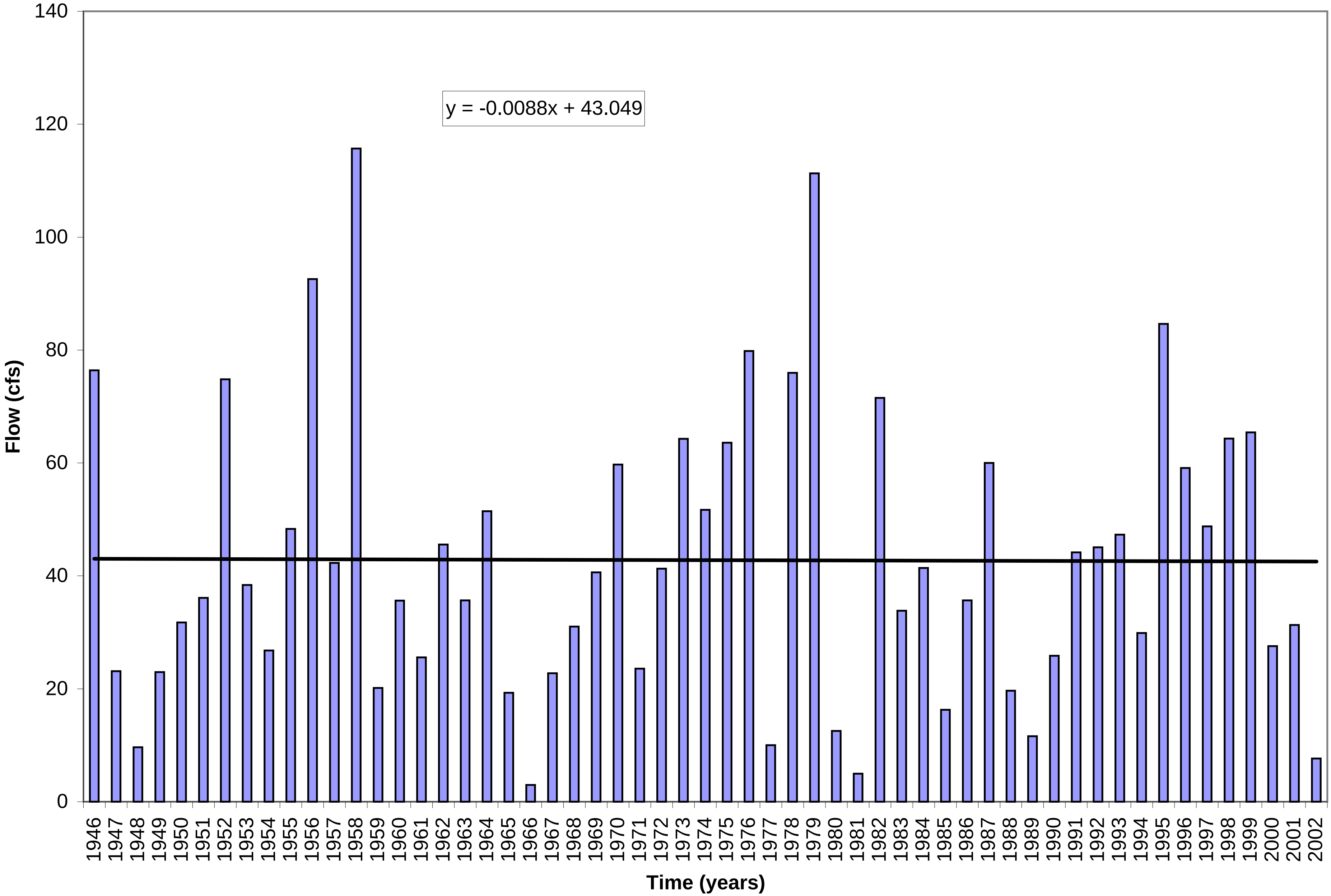


Figure A-2: Parker River USGS Gage at Byfield Average Monthly Flow for February

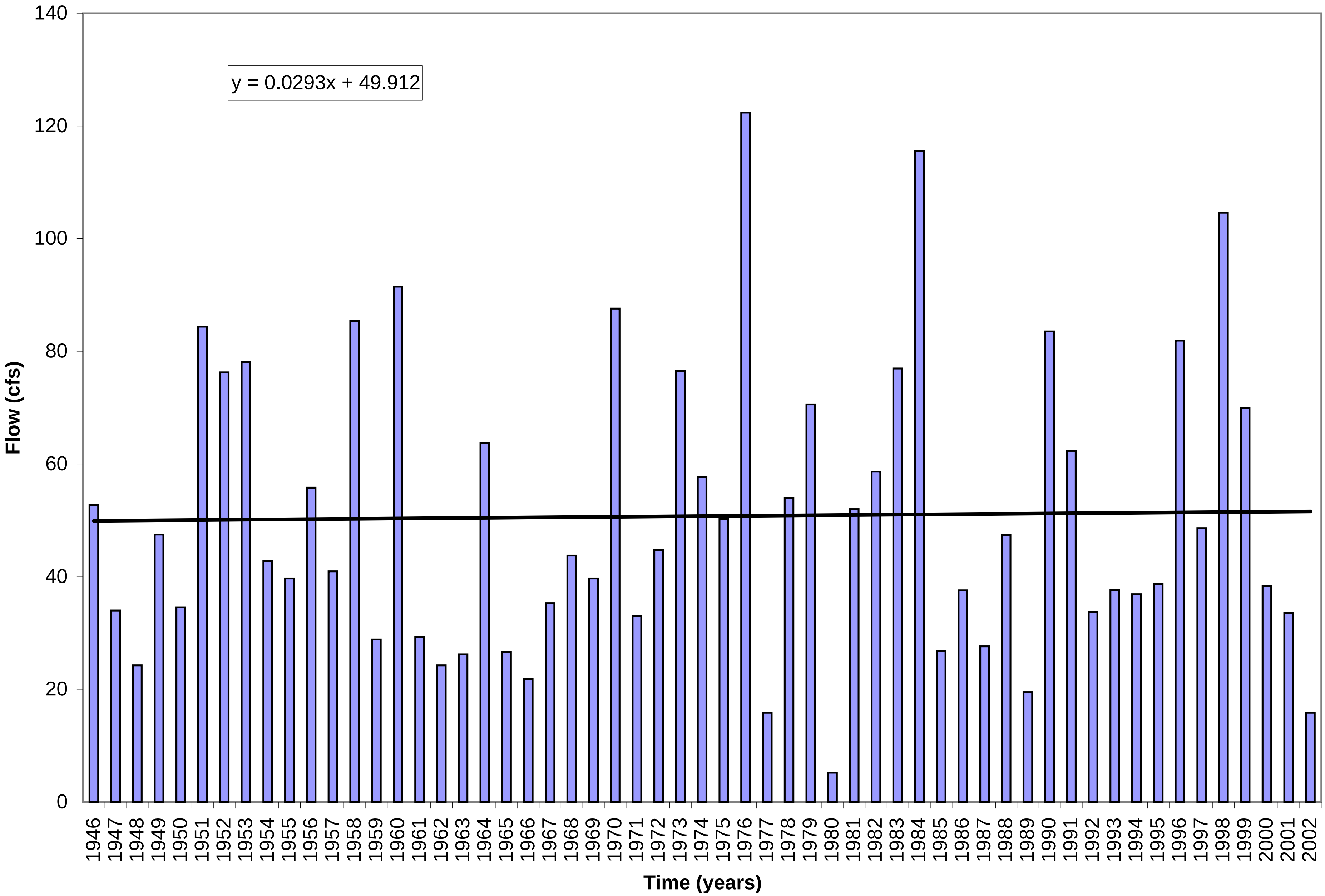


Figure A-3: Parker River USGS Gage at Byfield Average Monthly Flow for March

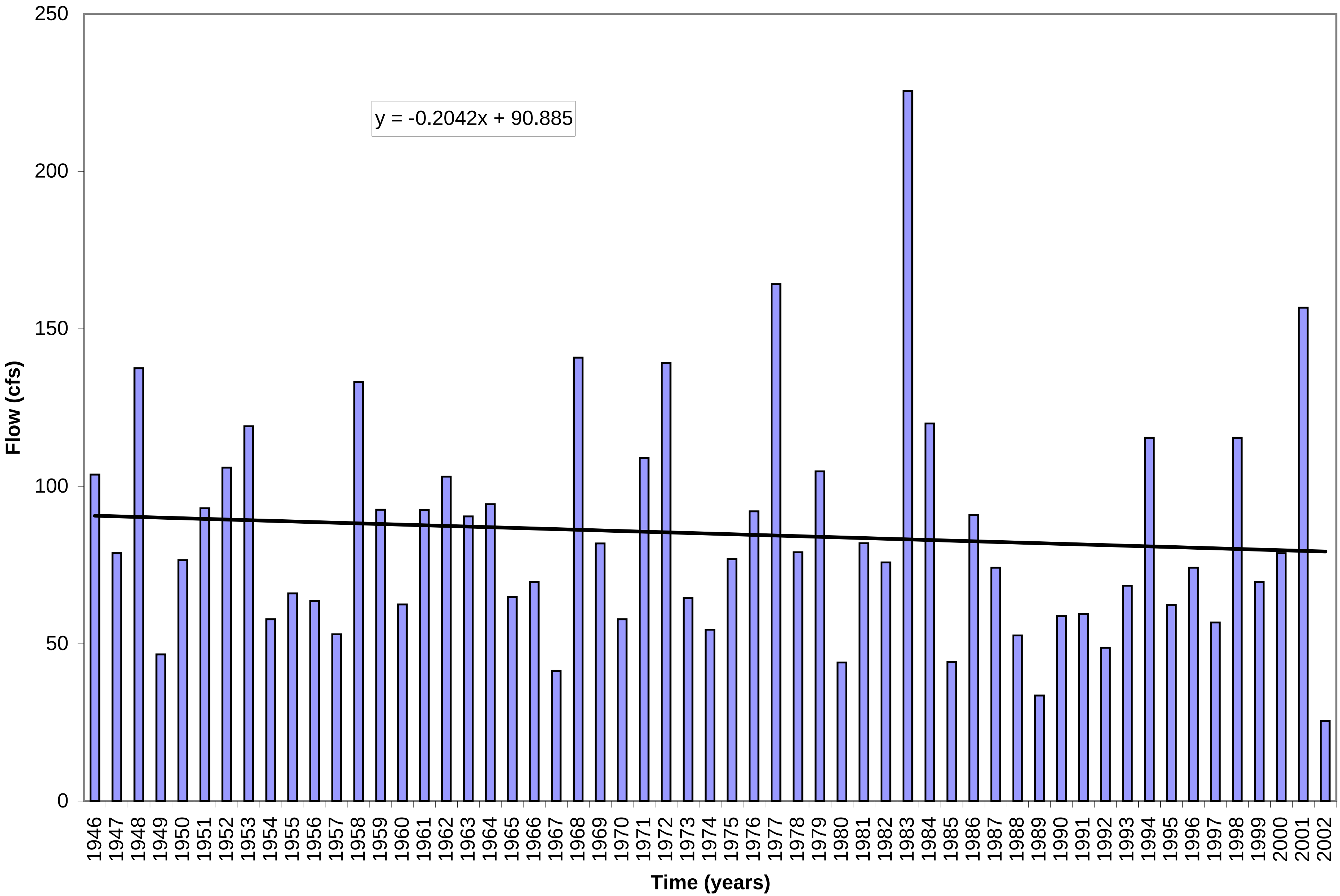


Figure A-4: Parker River USGS Gage at Byfield Average Monthly Flow for April

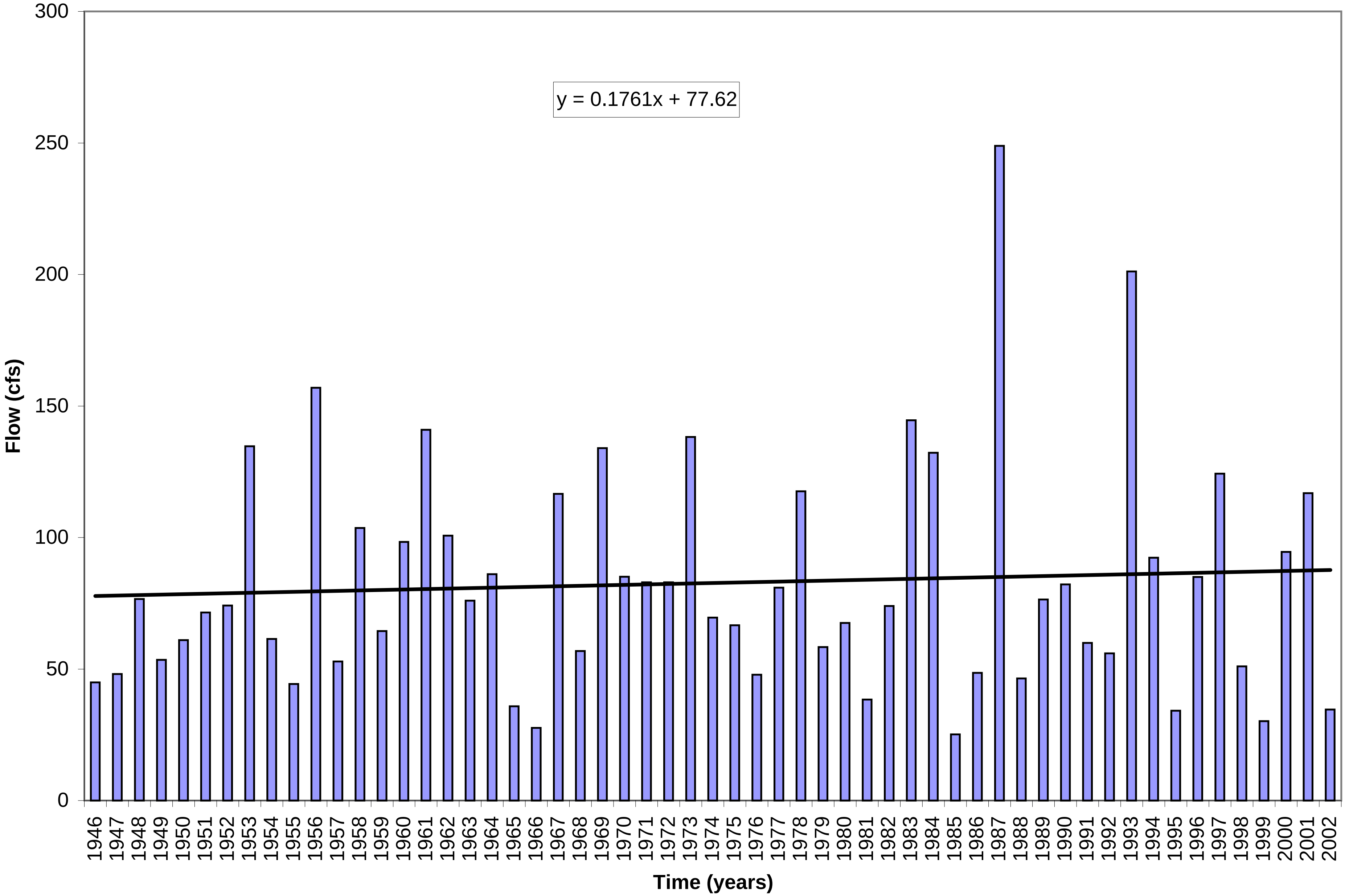


Figure A-5: Parker River USGS Gage at Byfield Average Monthly Flow for May

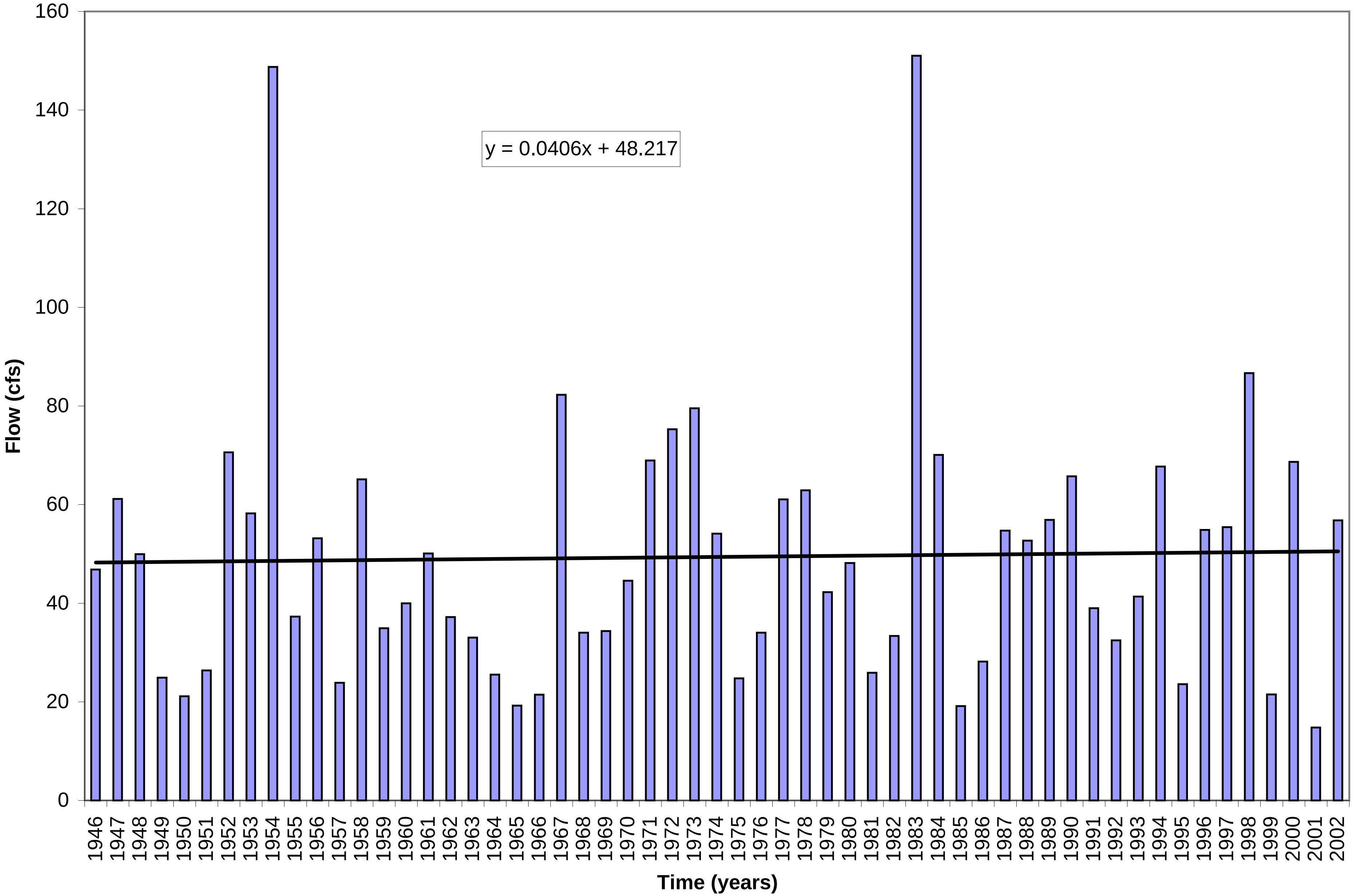


Figure A-6: Parker River USGS Gage at Byfield Average Monthly Flow for June

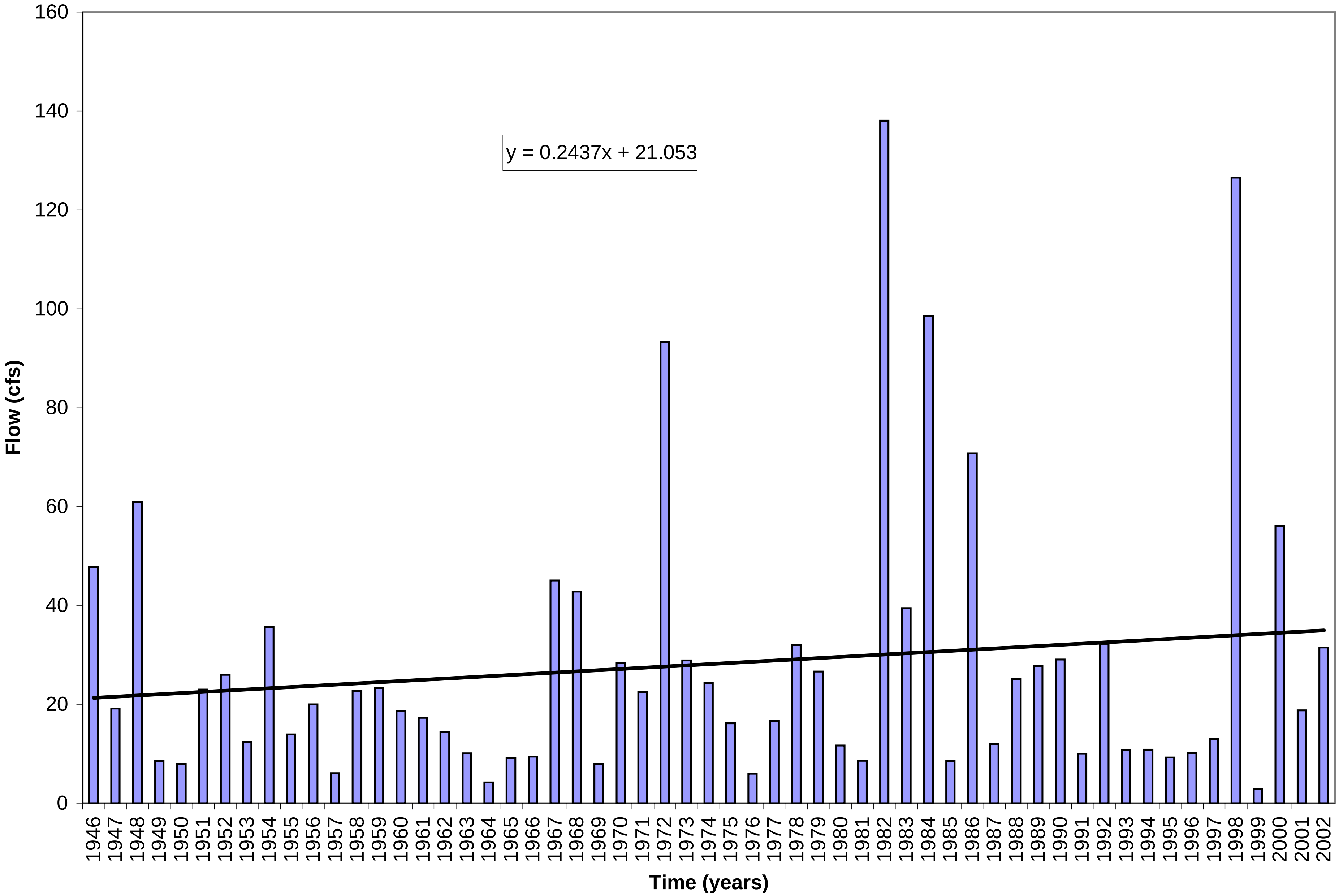


Figure A-7: Parker River USGS Gage at Byfield Average Monthly Flow for July

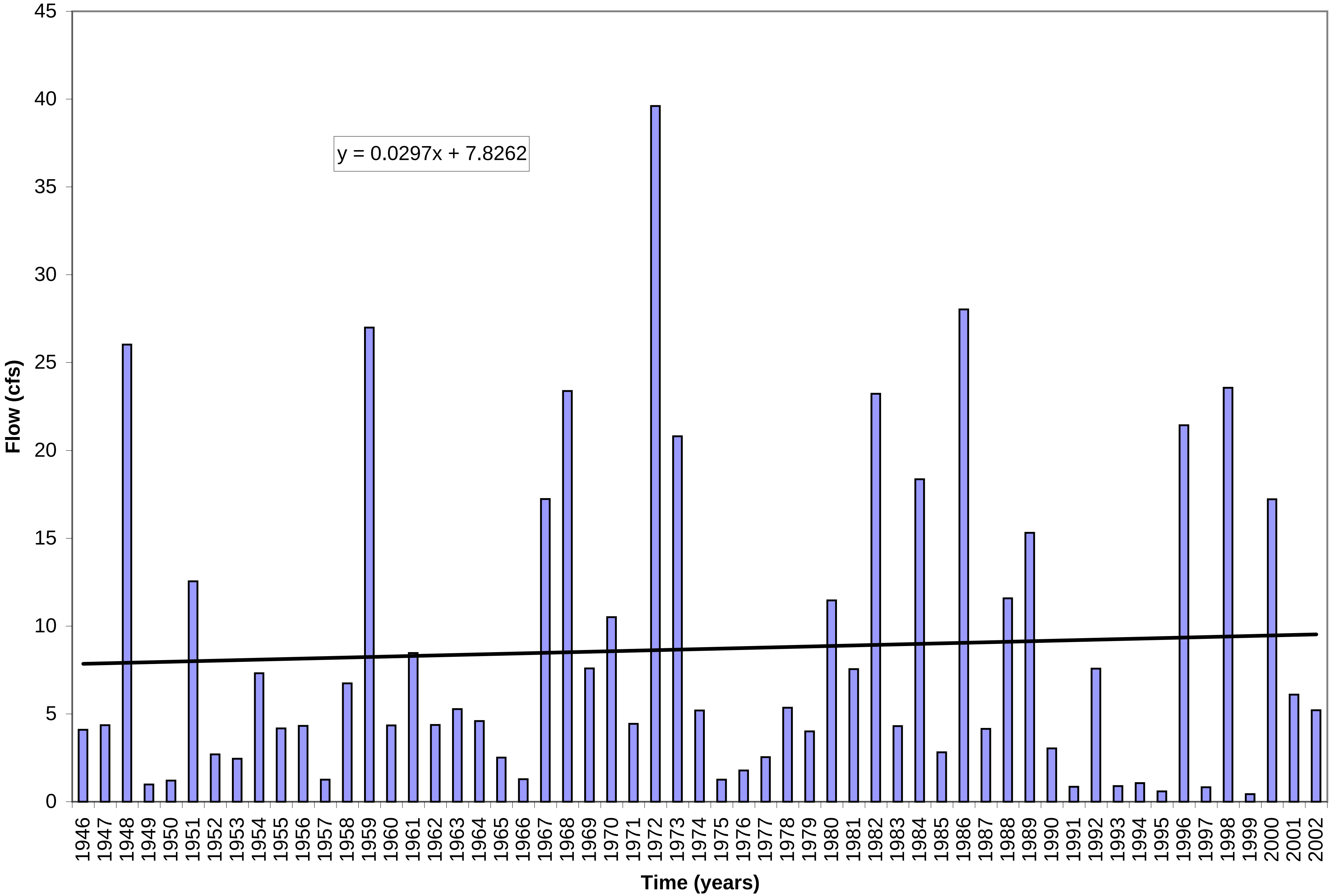


Figure A-8: Parker River USGS Gage at Byfield Average Monthly Flow for August

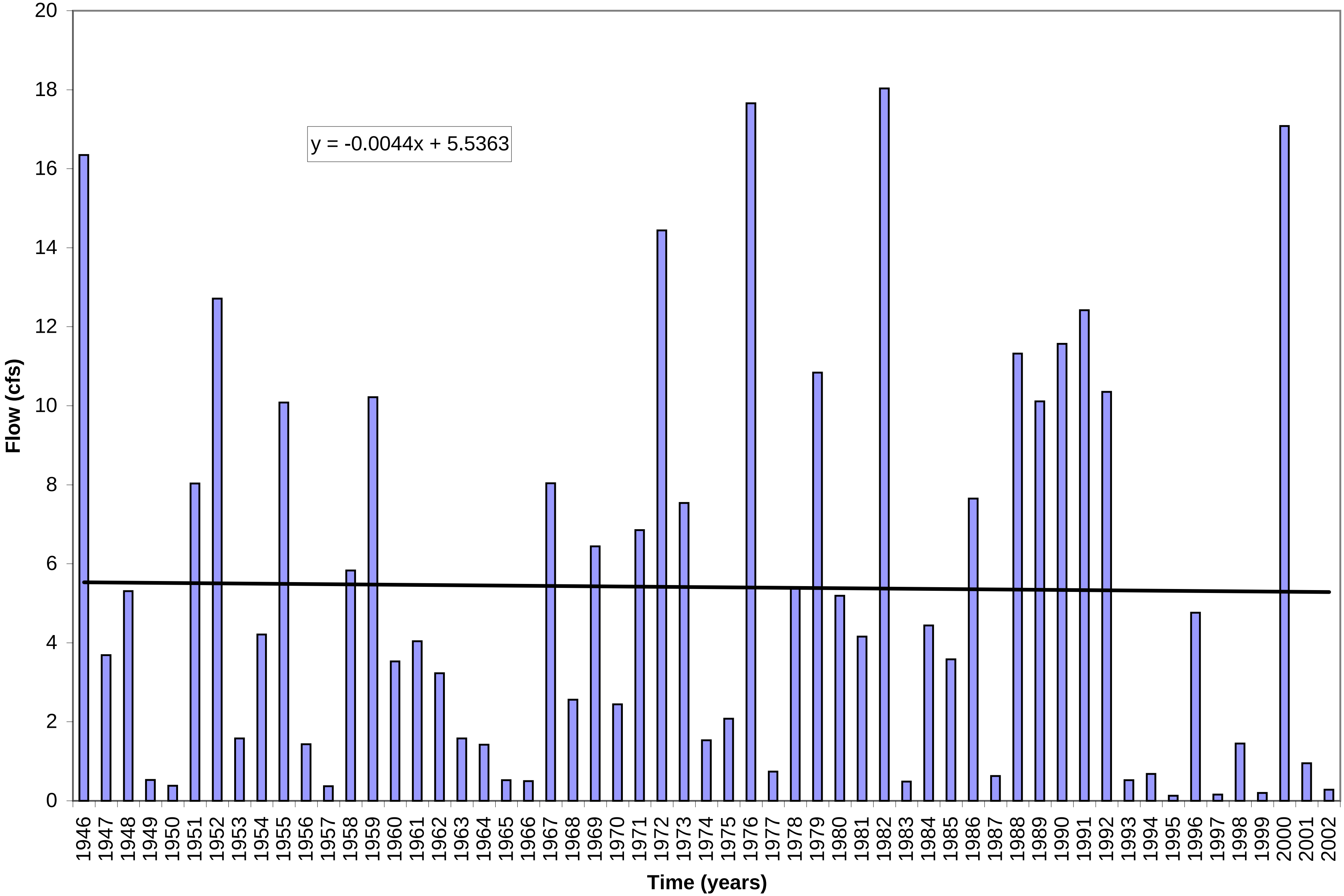


Figure A-9: Parker River USGS Gage at Byfield Average Monthly Flow for September

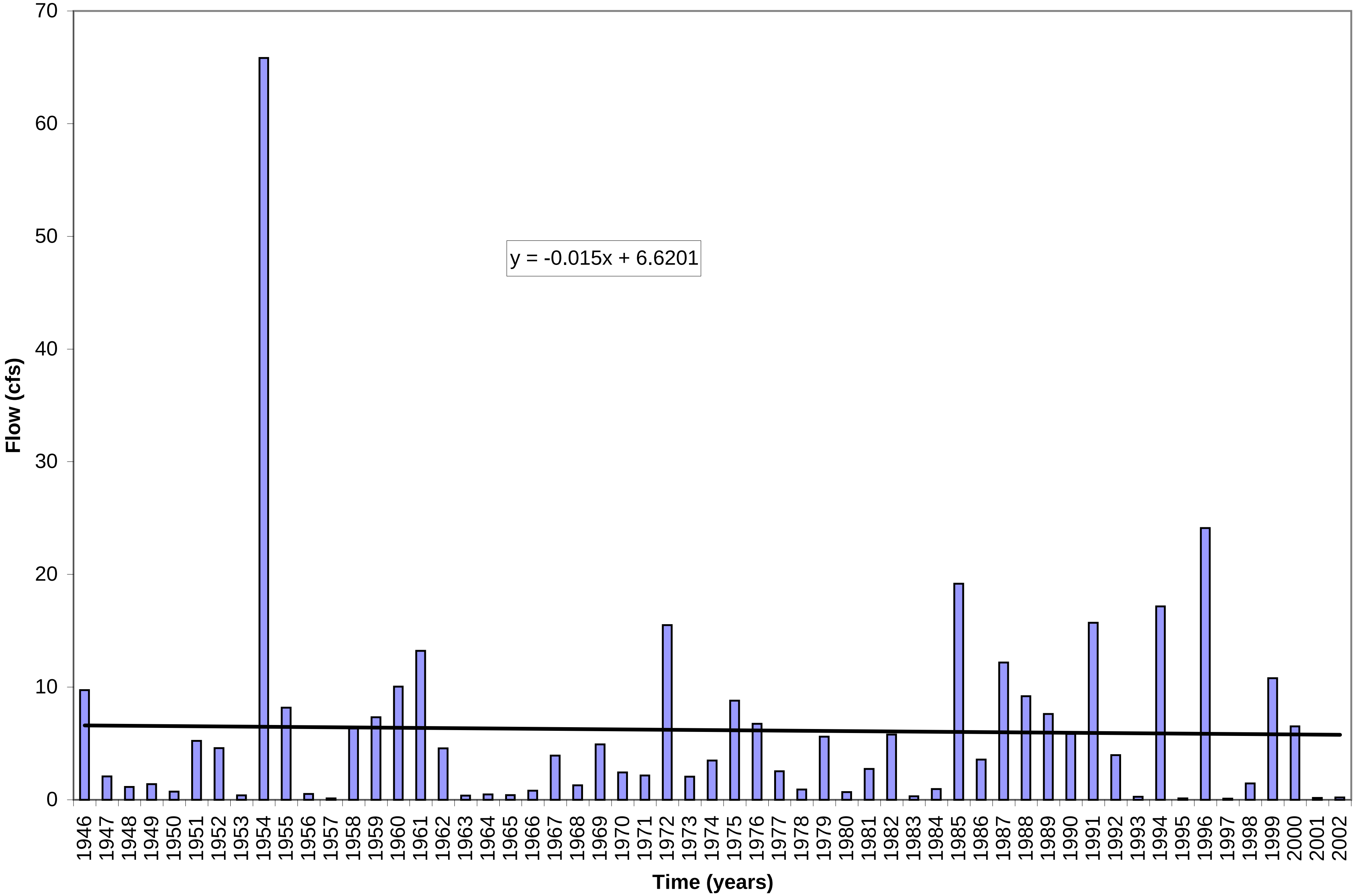
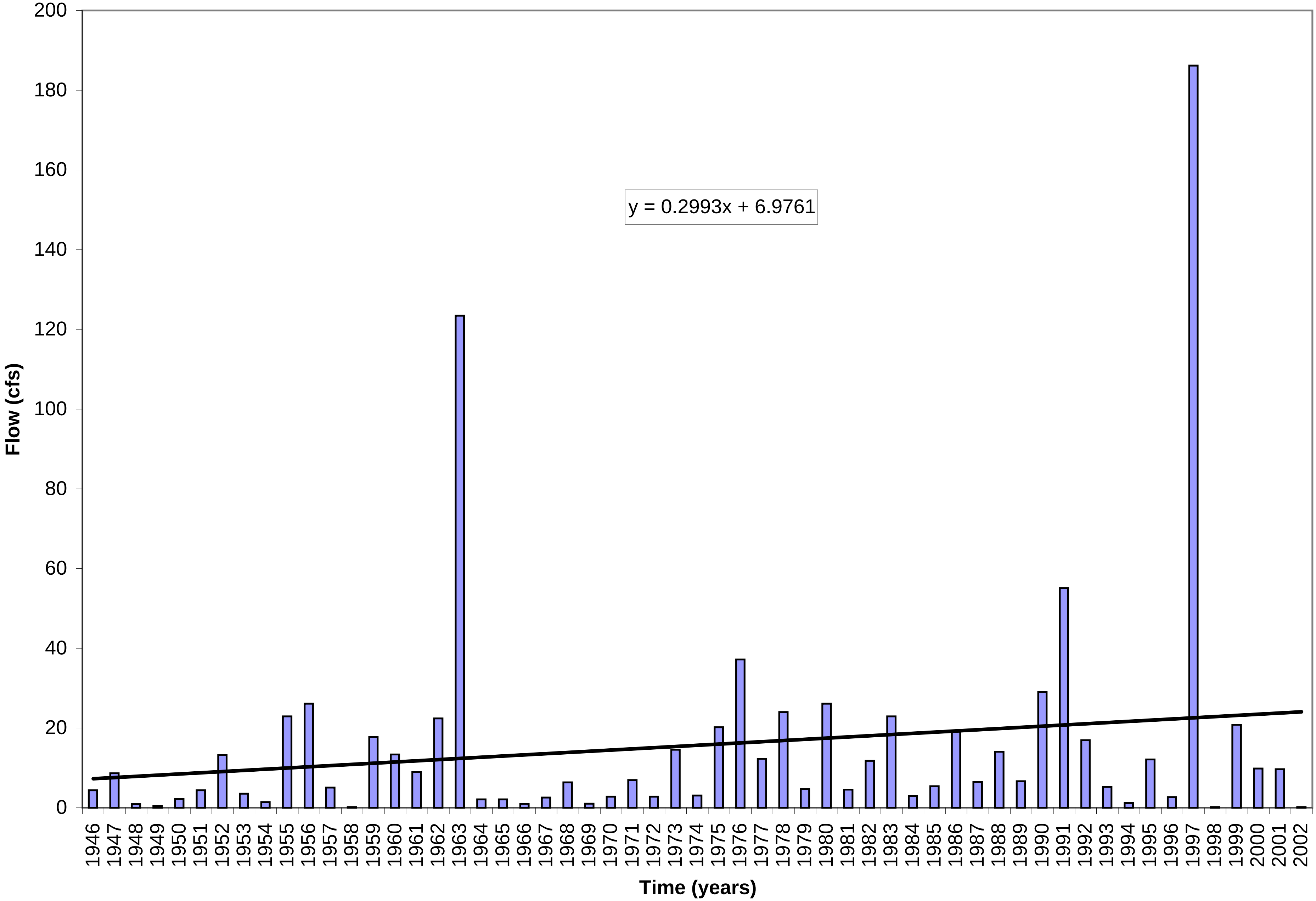


Figure A-10: Parker River USGS Gage at Byfield Average Monthly Flow for October



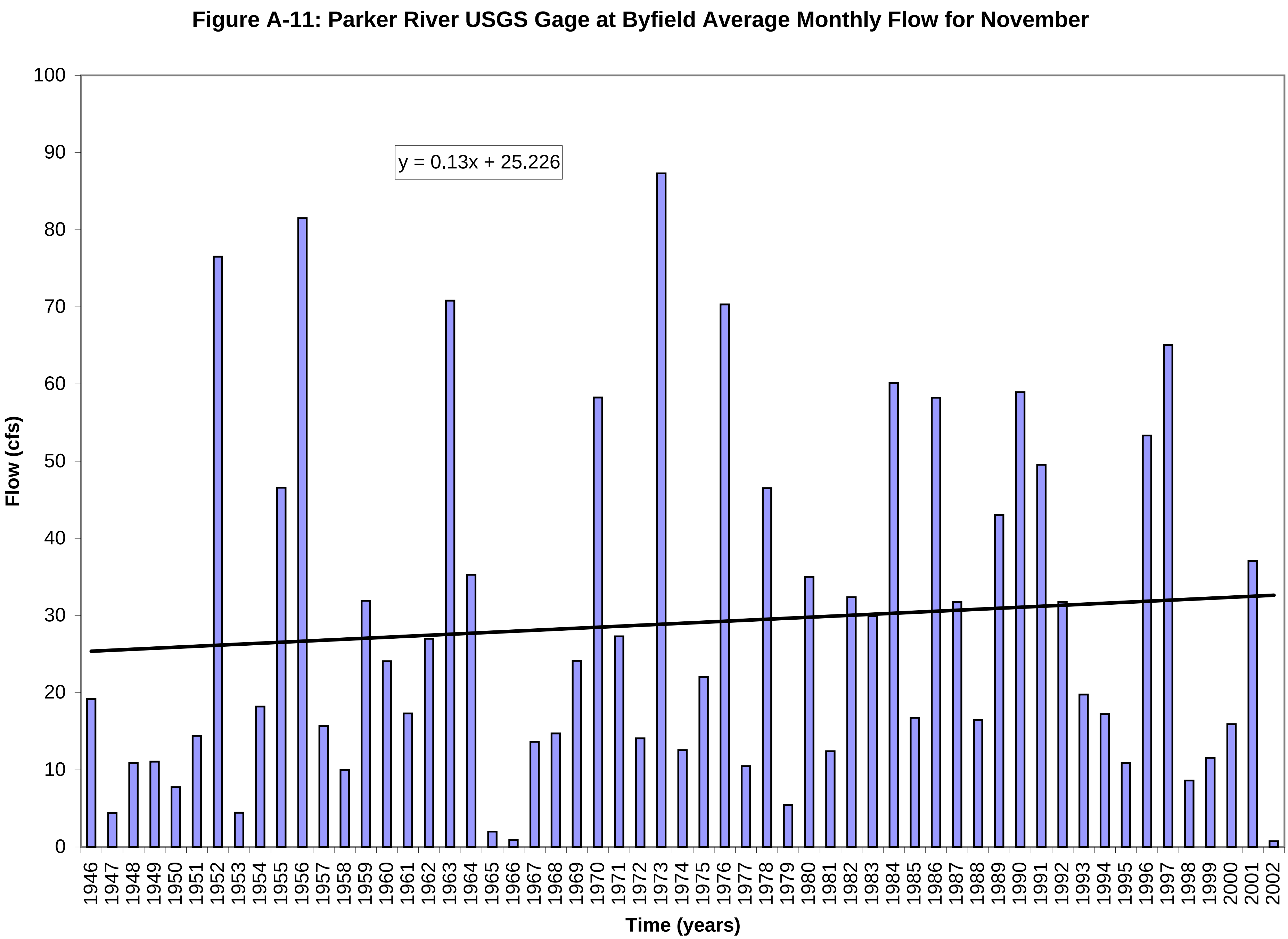


Figure A-11: Parker River USGS Gage at Byfield Average Monthly Flow for November
y = 0.13x + 25.226
Flow (cfs)
0
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60
70
80
90
100
1946
1947
1948
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1996
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2000
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2002
Time (years)

Figure A-12: Parker River USGS Gage at Byfield Average Monthly Flow for December

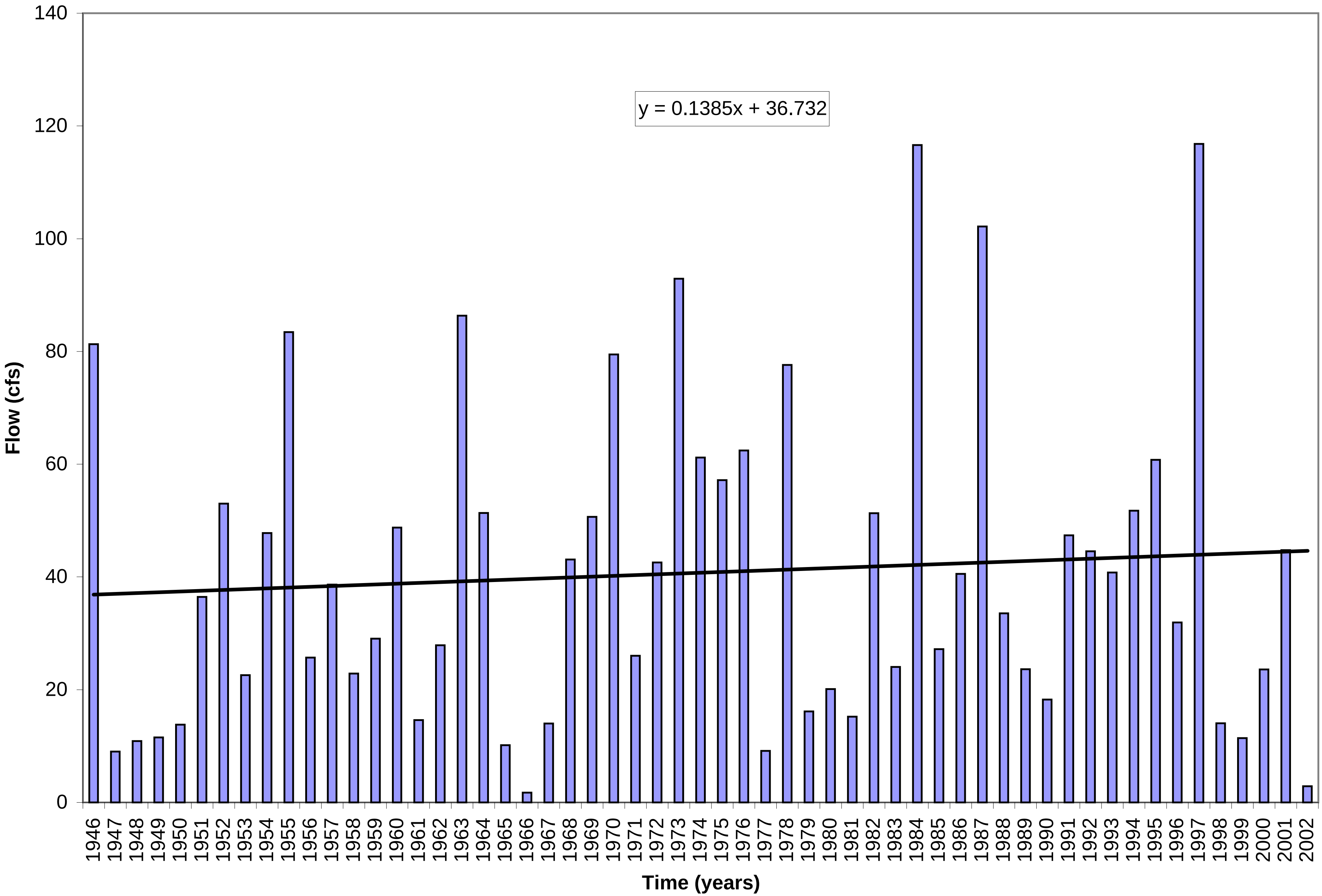


Figure A-13: Parker River USGS Gage at Byfield Base Flow

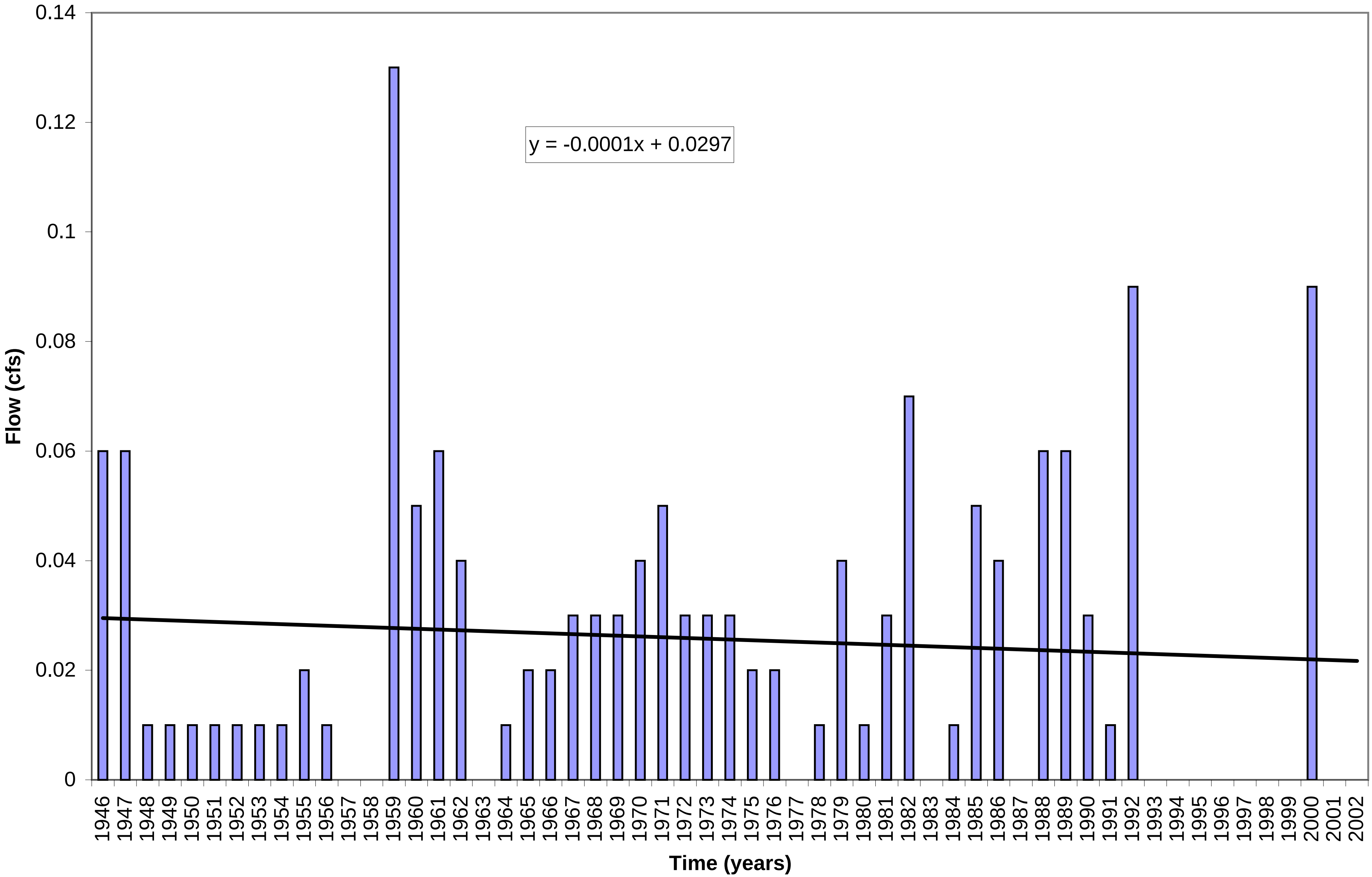


Figure A-14: Parker River USGS Gage at Byfield 1-Day Average Minimum Flow

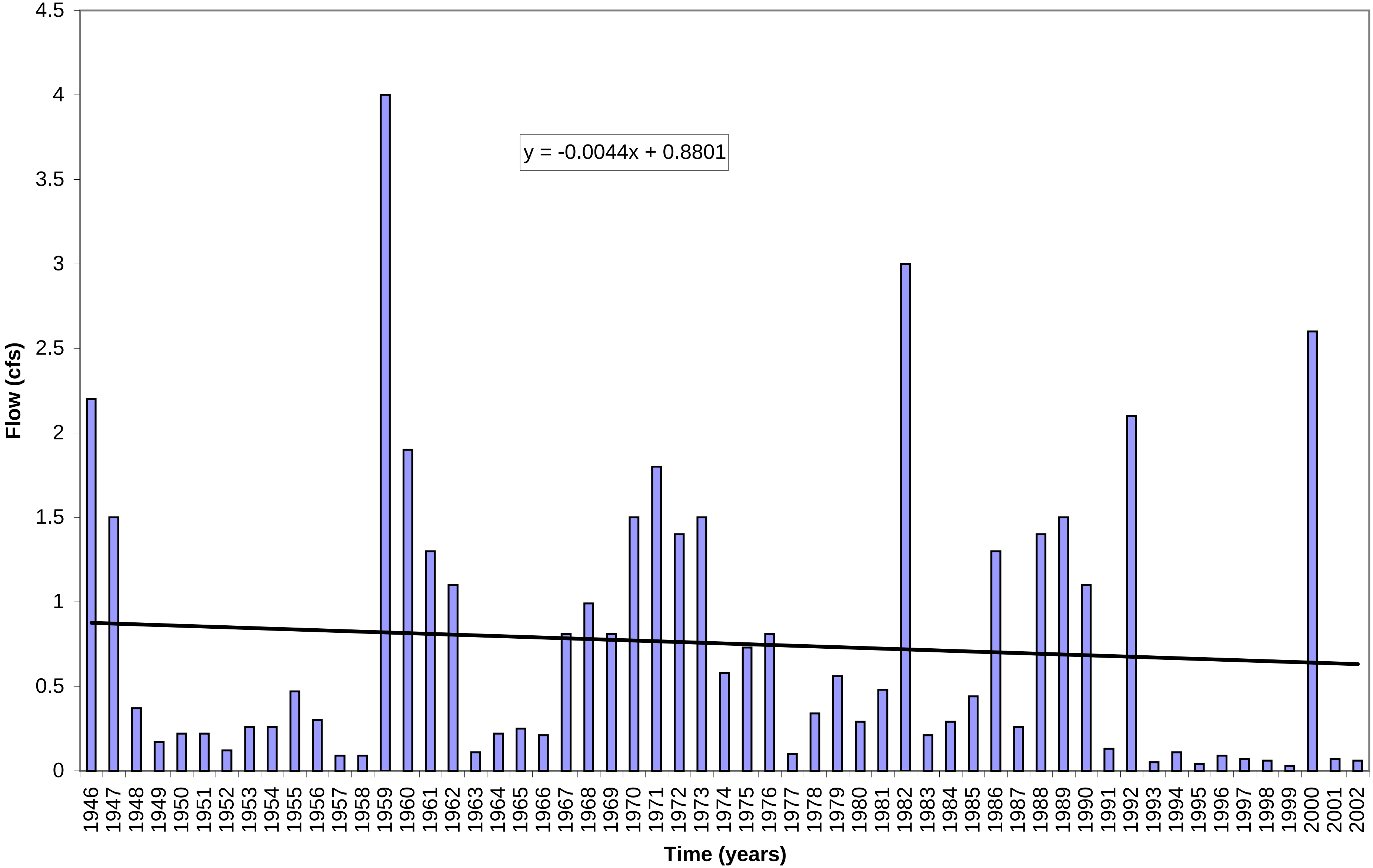


Figure A-15: Parker River USGS Gage at Byfield 3-Day Average Minimum Flow

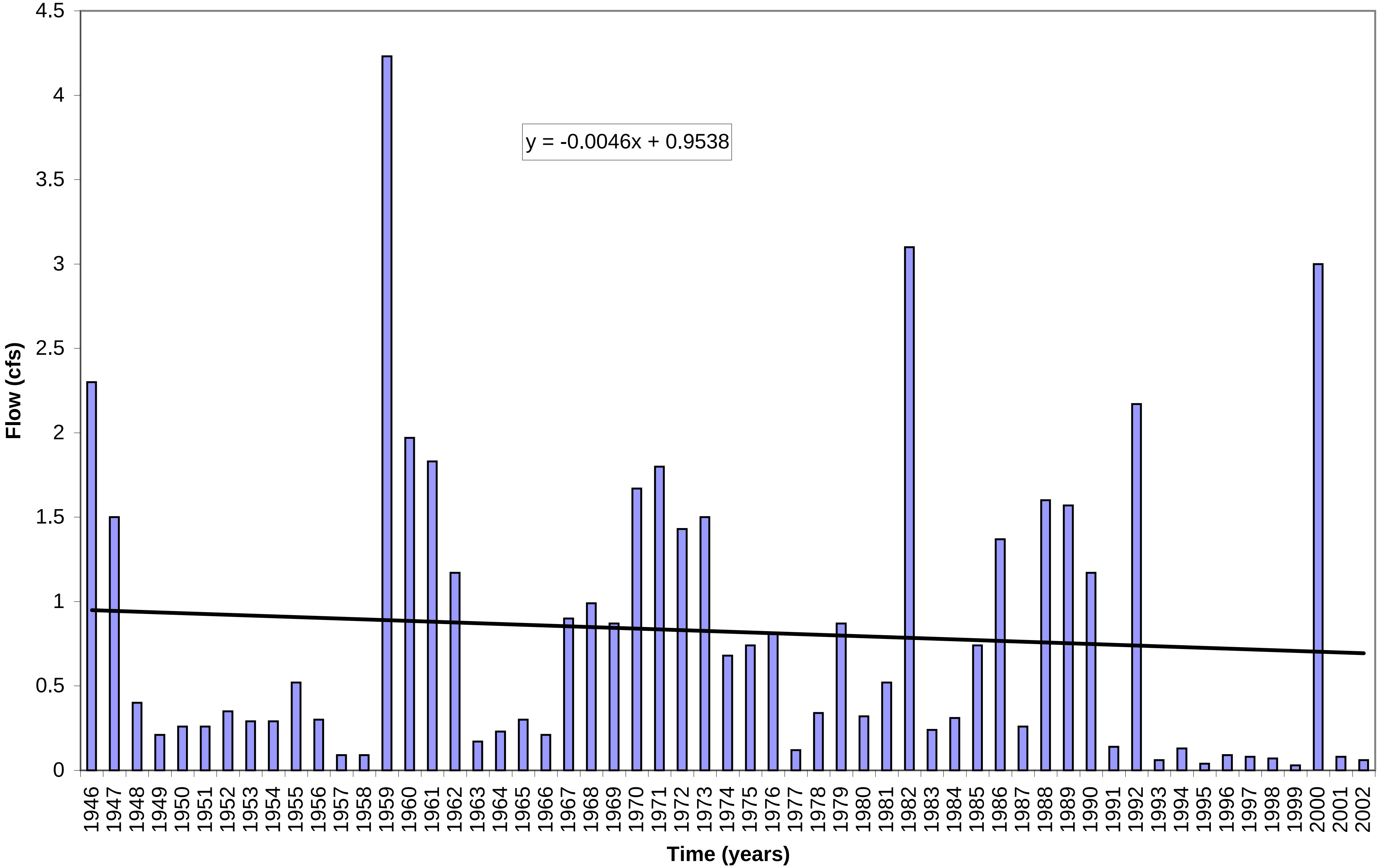


Figure A-16: Parker River USGS Gage at Byfield 7-Day Average Minimum Flow

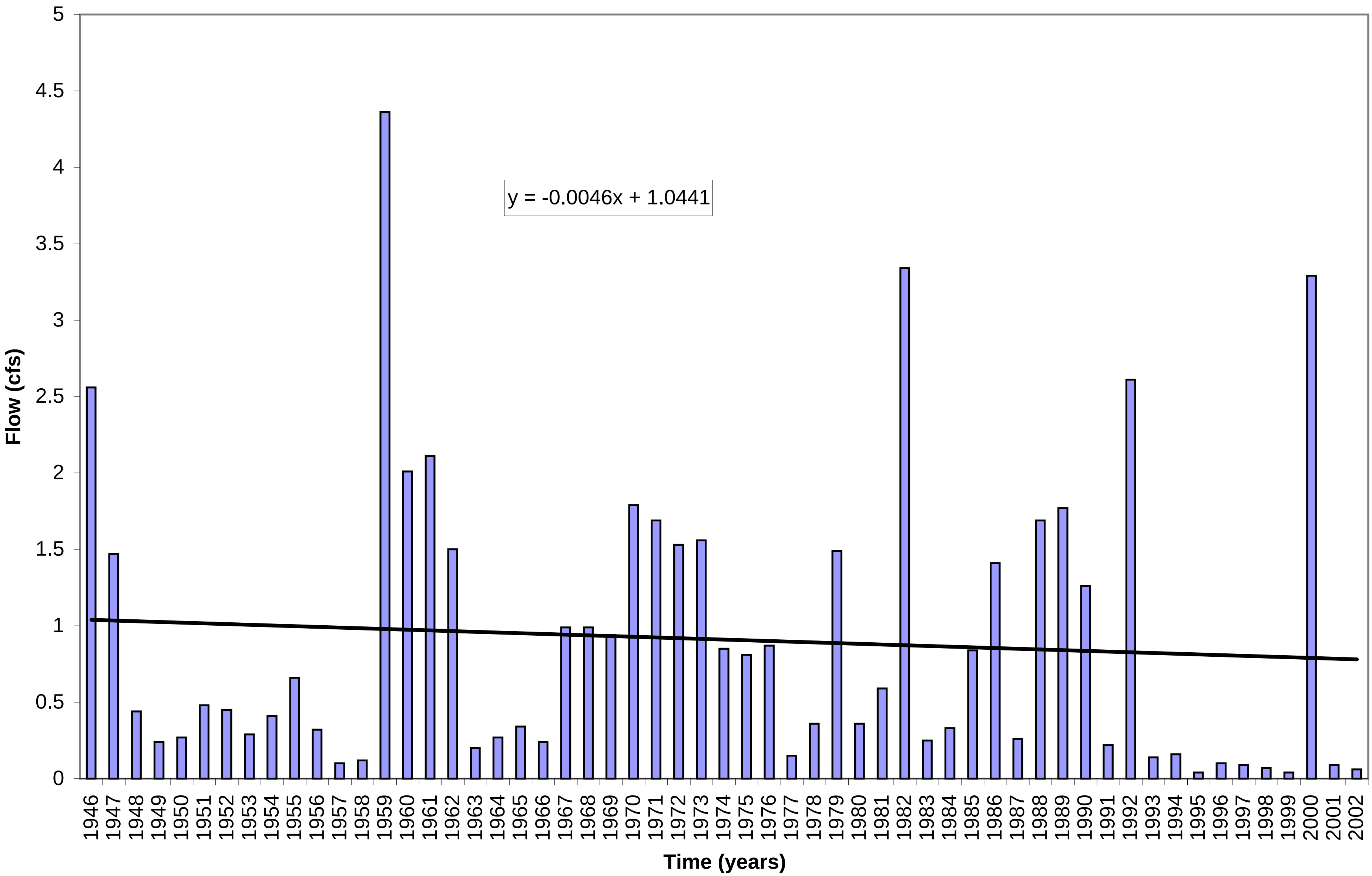


Figure A-17: Parker River USGS Gage at Byfield 30-Day Average Minimum Flow

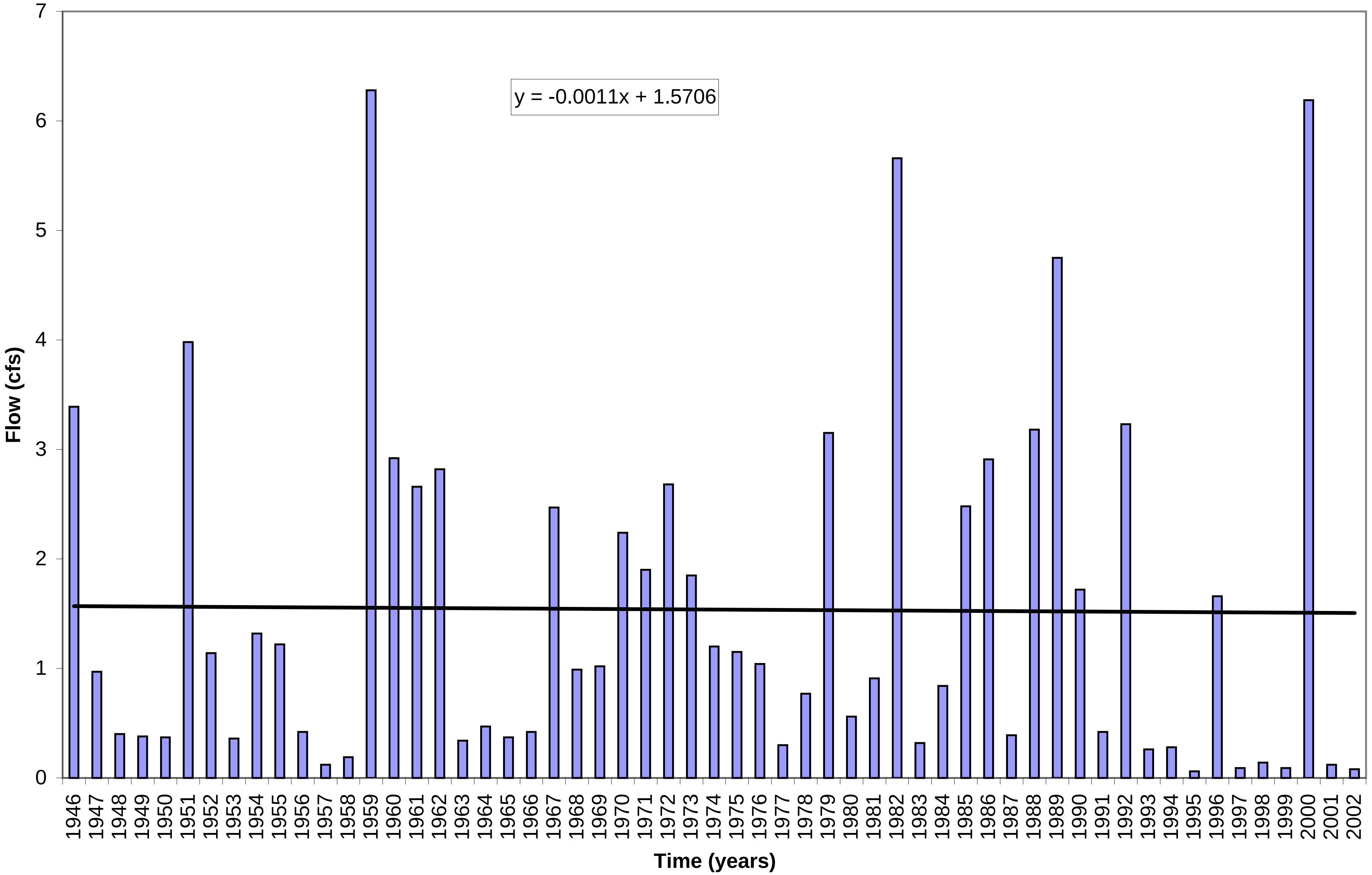


Figure A-18: Parker River USGS Gage at Byfield 90-Day Average Minimum Flow

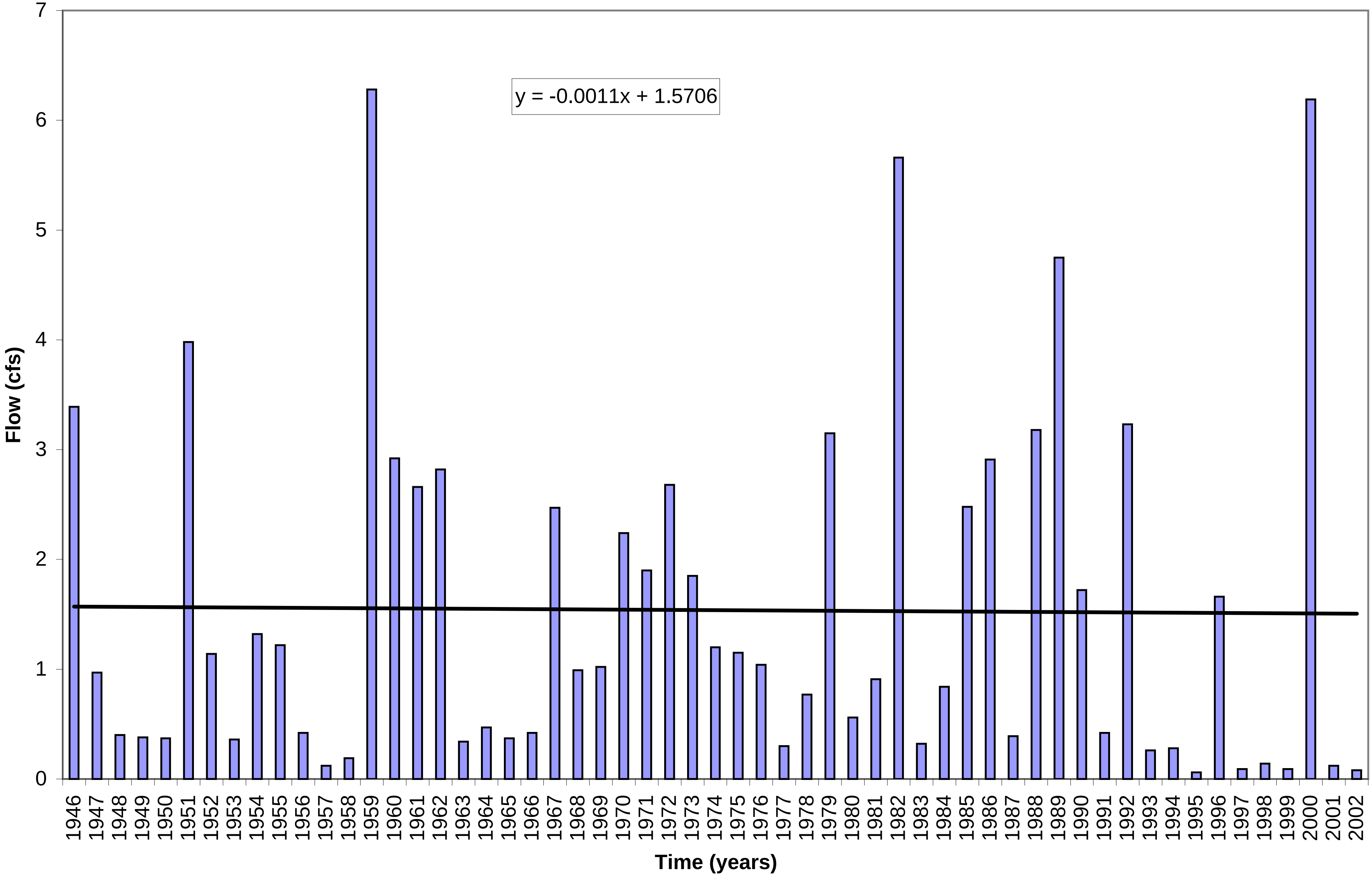


Figure A-19: Parker River USGS Gage at Byfield 1-Day Average Maximum Flow

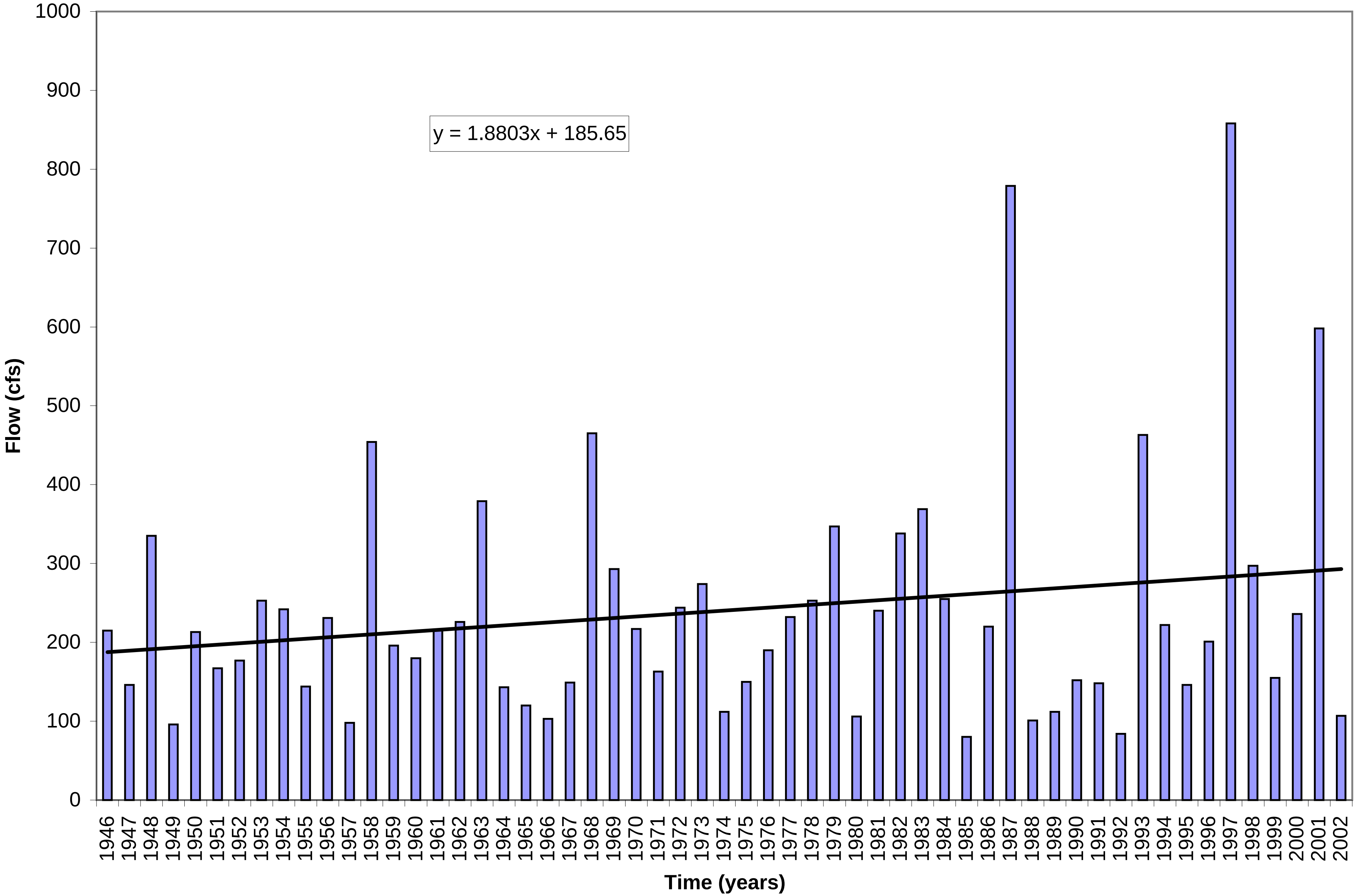


Figure A-20: Parker River USGS Gage at Byfield 3-Day Average Maximum Flow

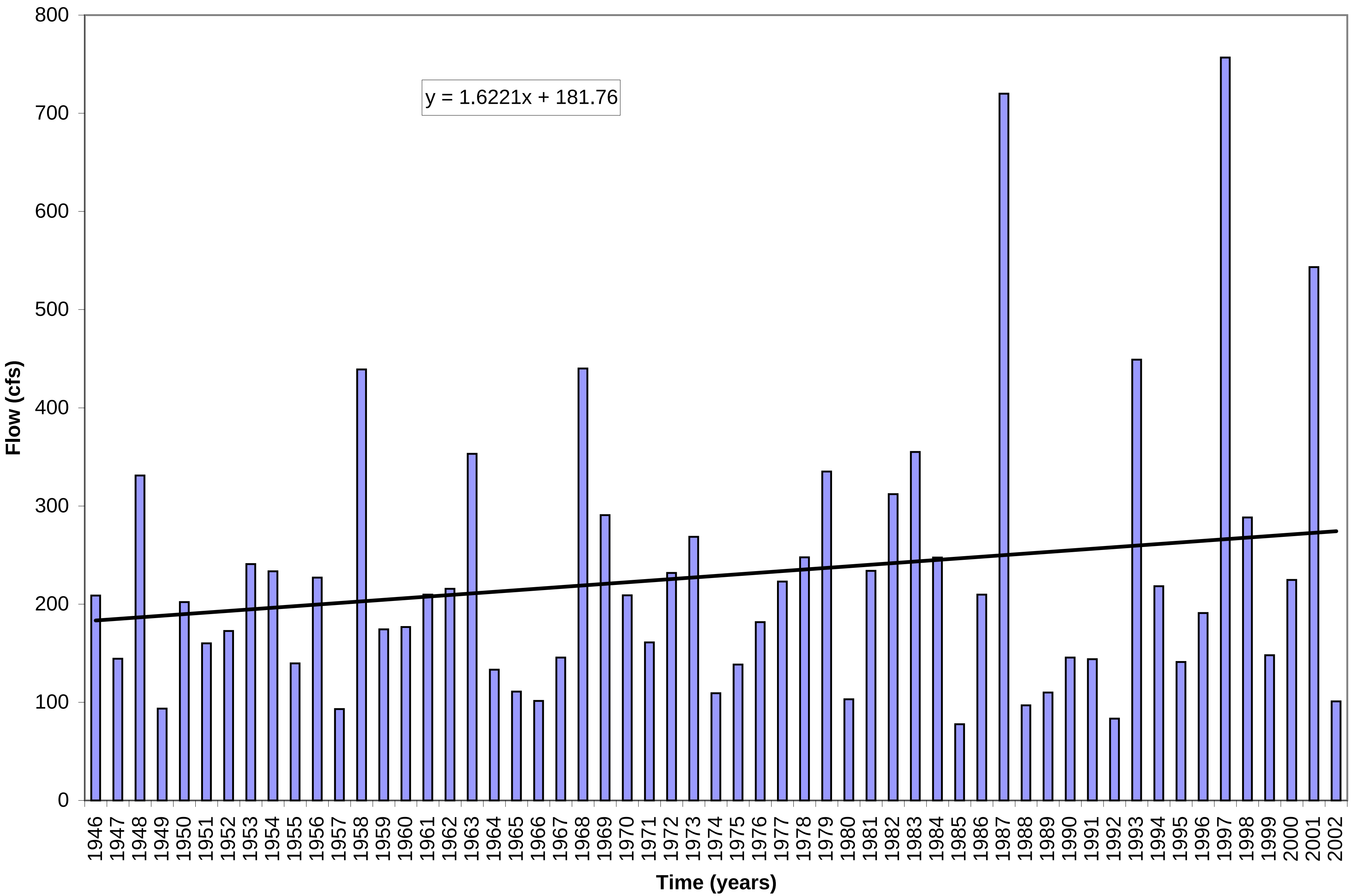


Figure A-21: Parker River USGS Gage at Byfield 7-Day Average Maximum Flow

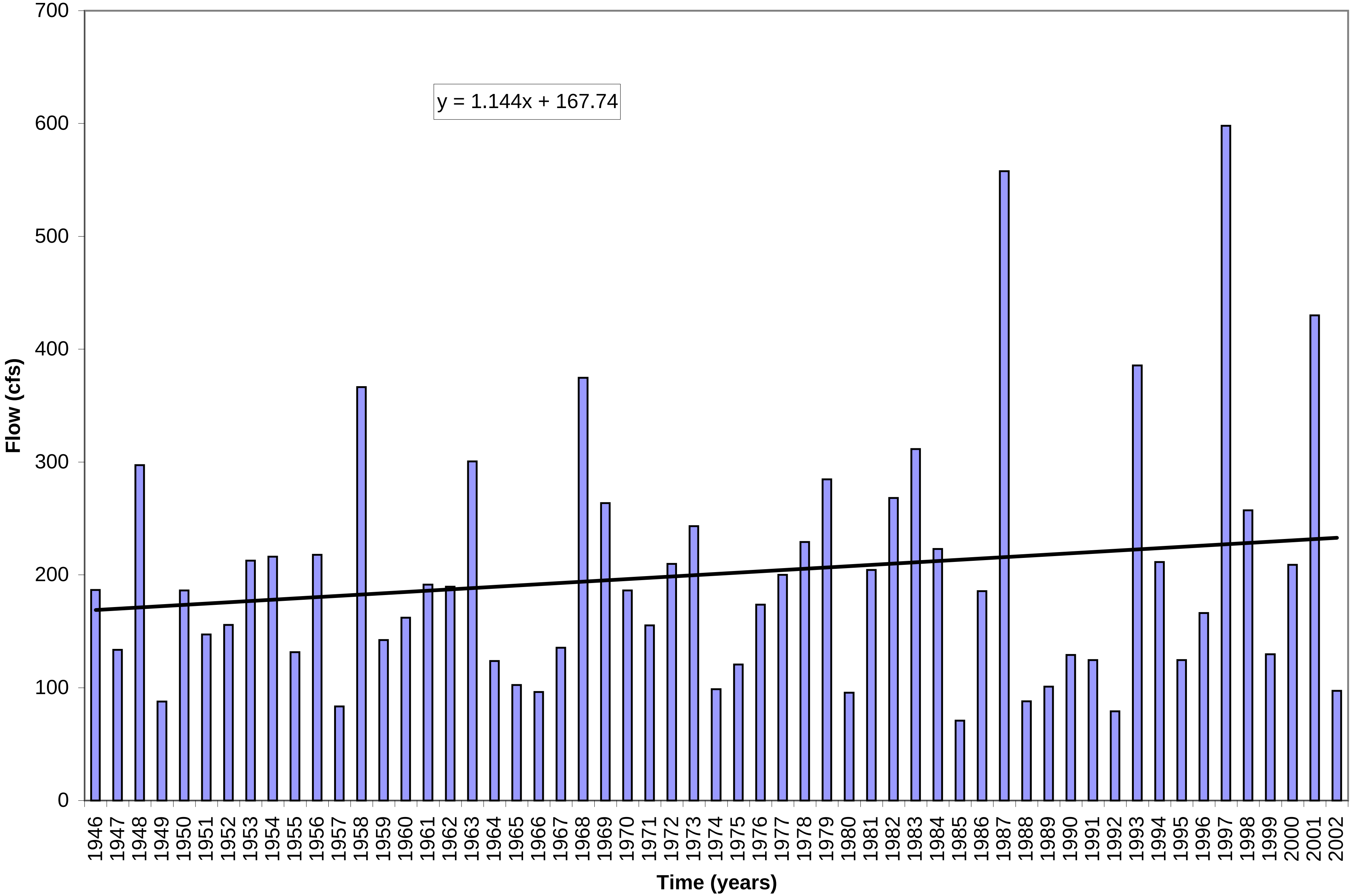


Figure A-22: Parker River USGS Gage at Byfield 30-Day Average Maximum Flow

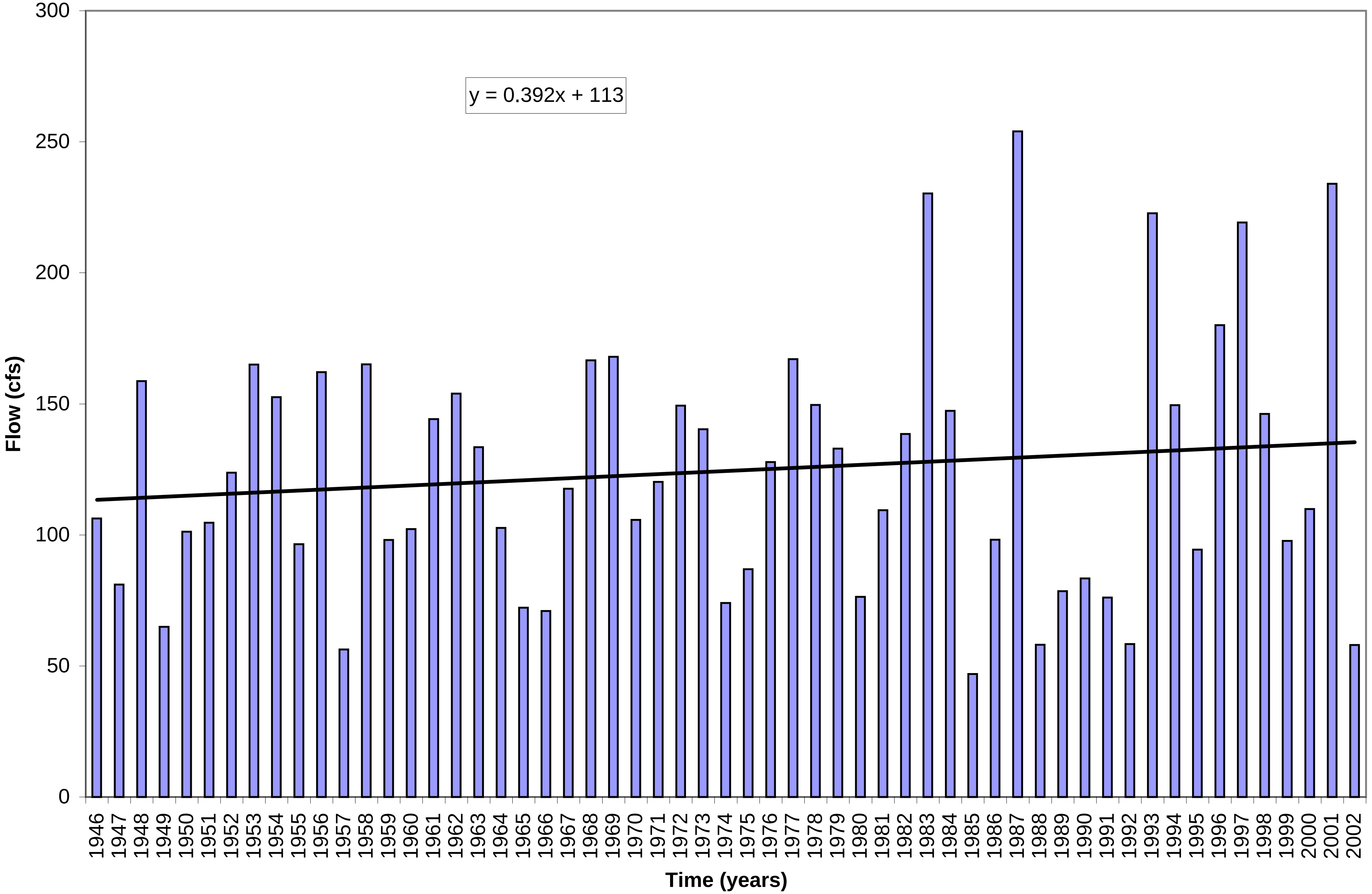


Figure A-23: Parker River USGS Gage at Byfield 90-Day Average Maximum Flow

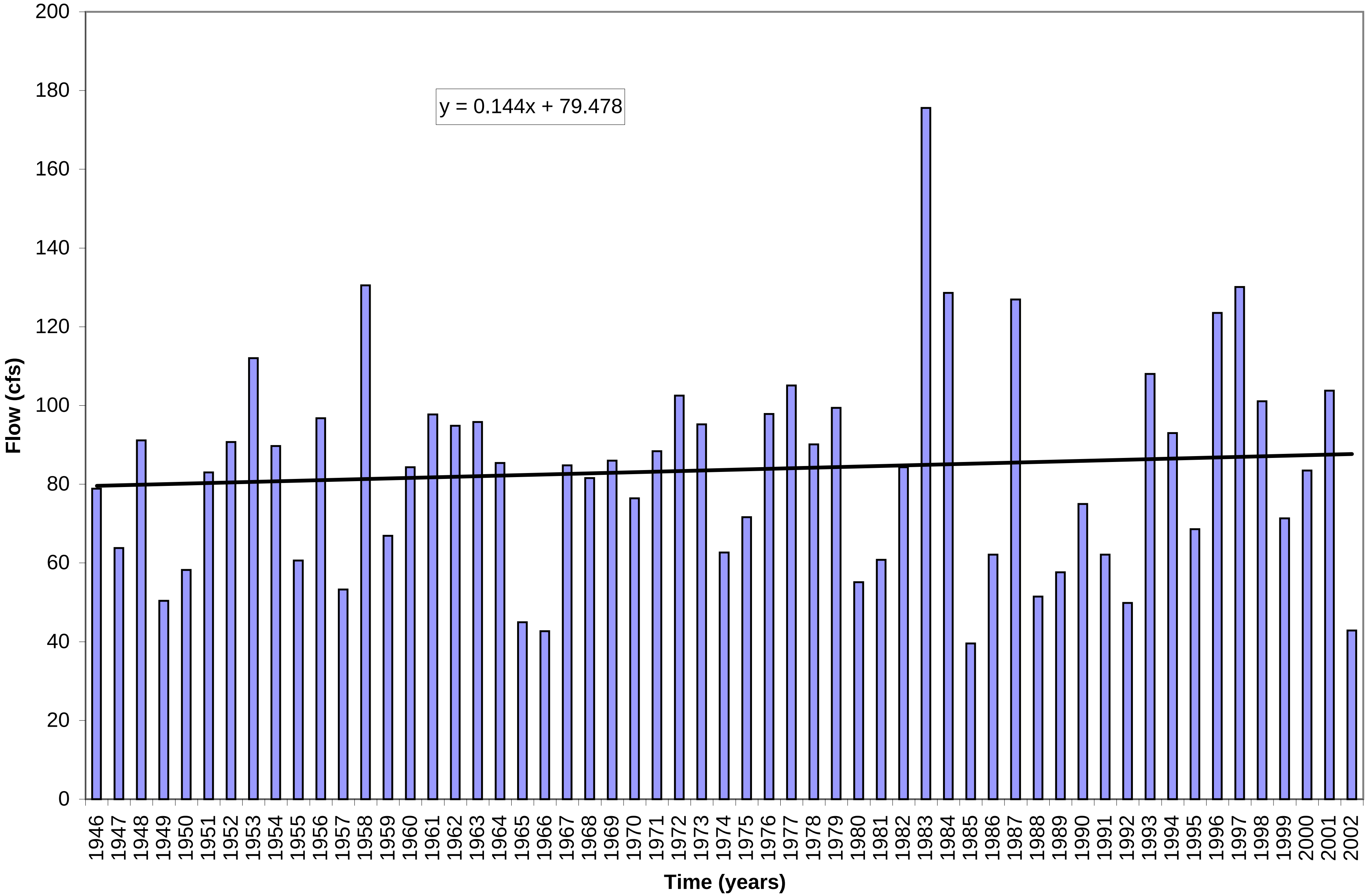


Figure A-24: Parker River USGS Gage at Byfield Julian Date of Annual 1-Day Maximum Flow

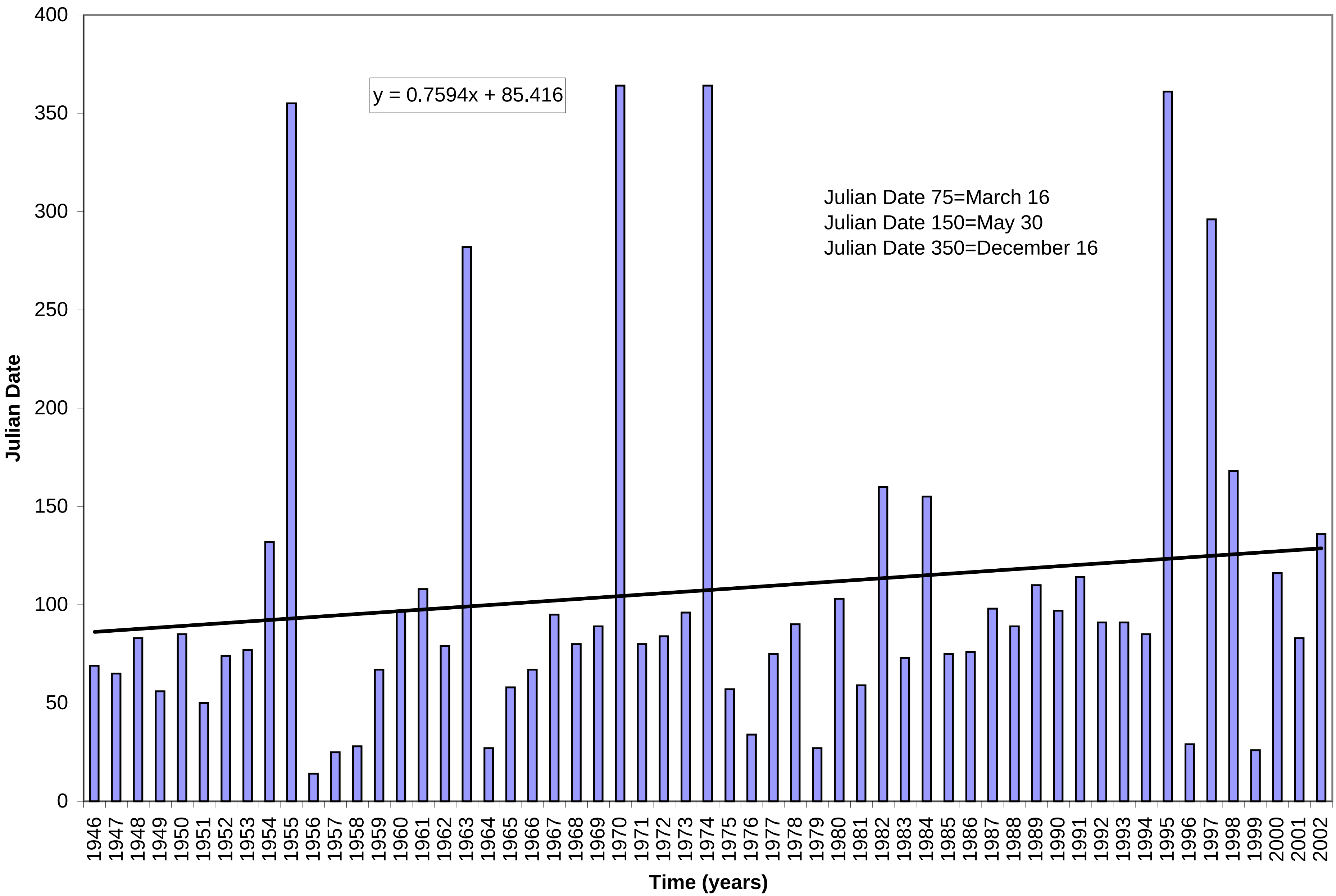


Figure A-25: Parker River USGS Gage at Byfield Julian Date of Annual 1-Day Minimum Flow

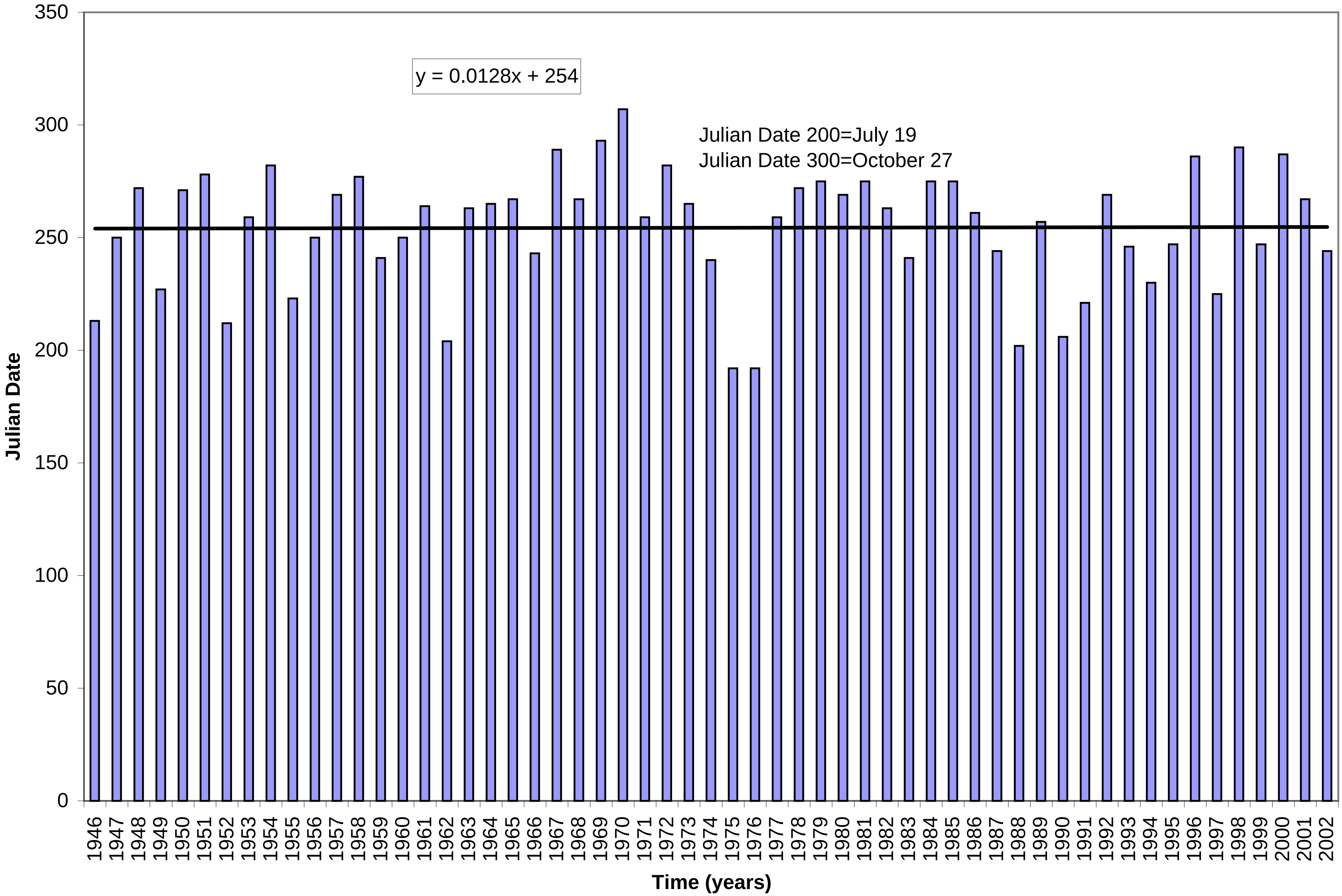


Figure A-26: Parker River USGS Gage at Byfield Number of Low Pulses

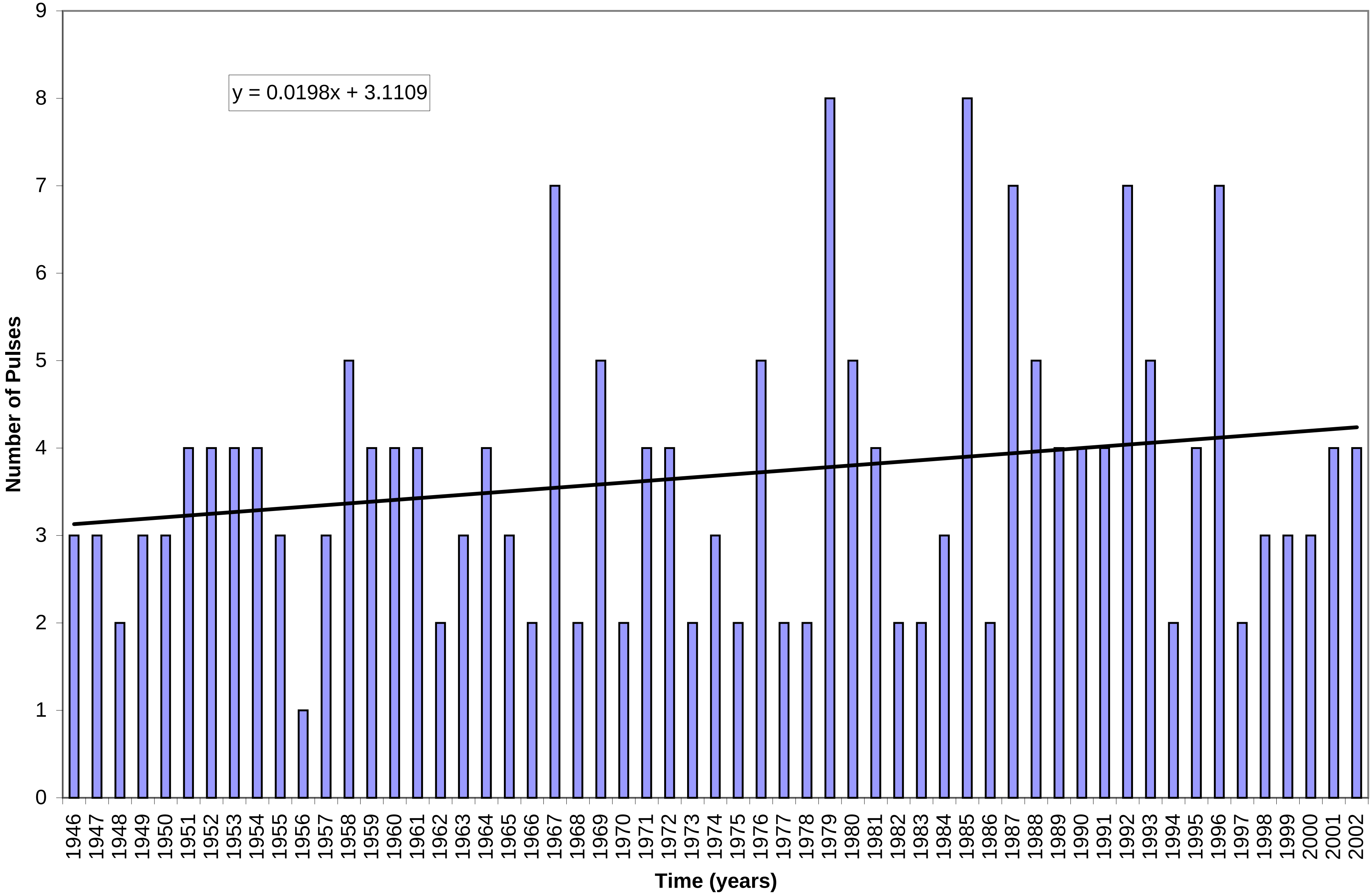


Figure A-27: Parker River USGS Gage at Byfield Number of High Pulses

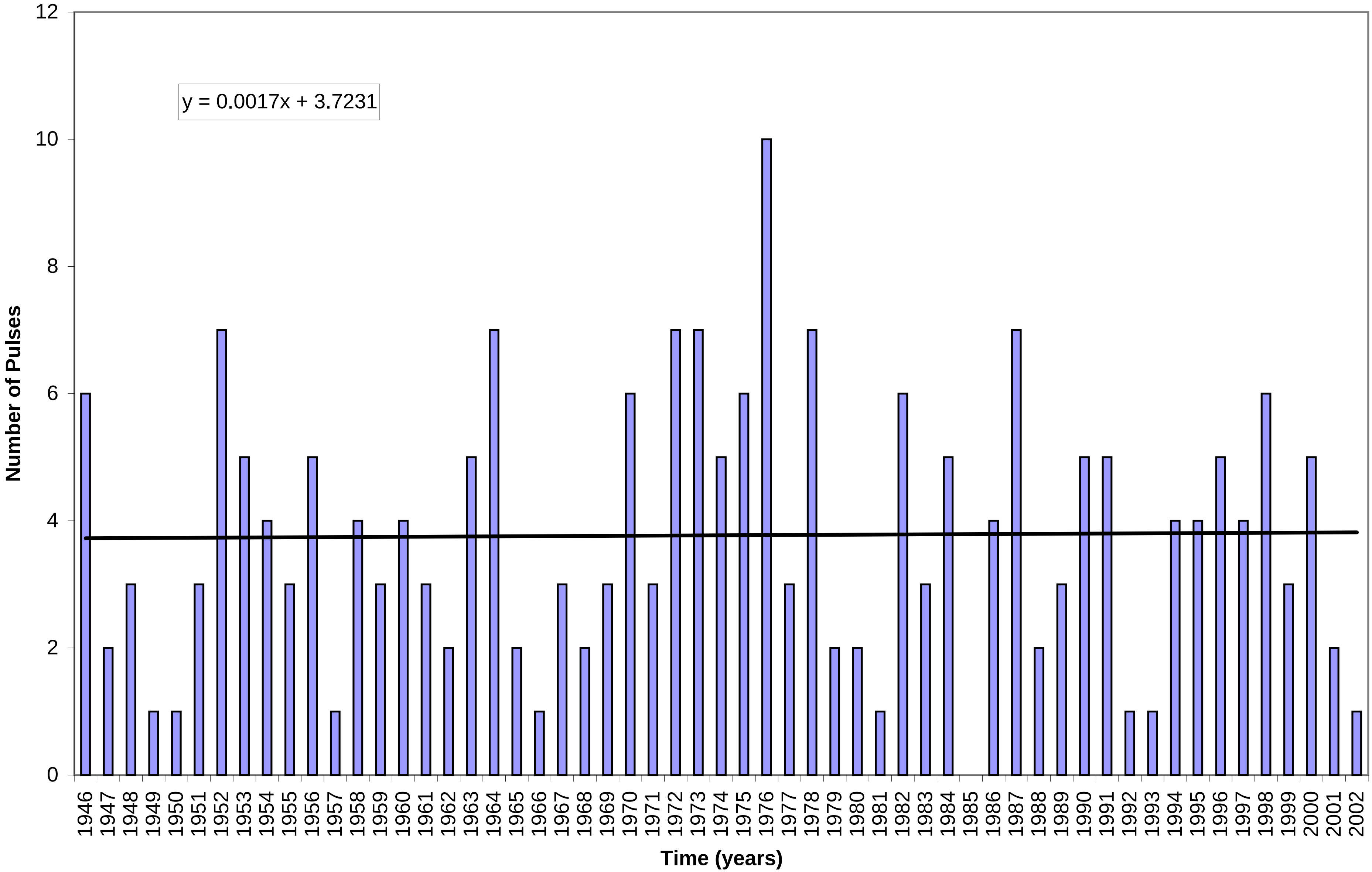


Figure A-28: Parker River USGS Gage at Byfield Low Pulse Duration

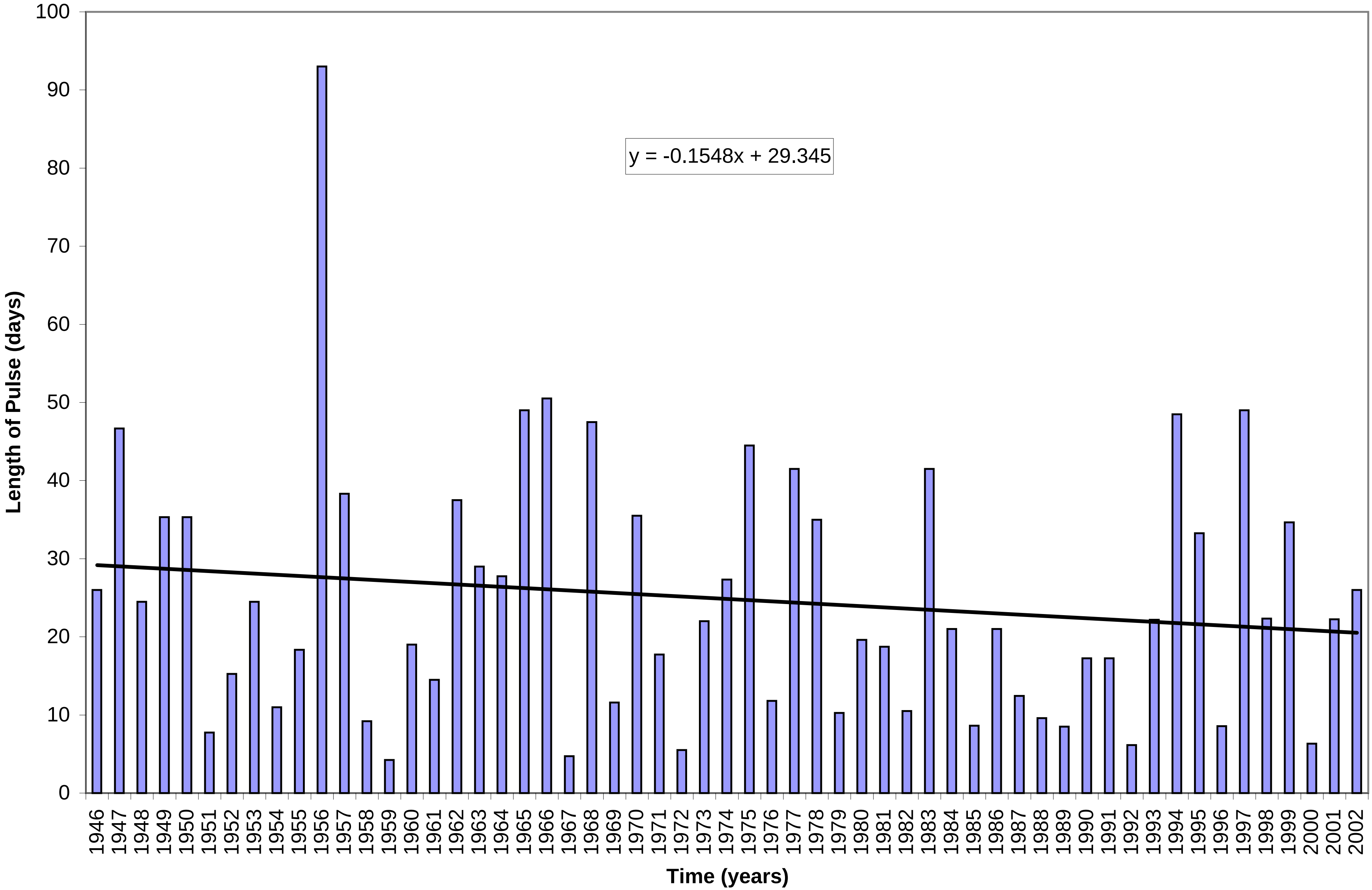


Figure A-29: Parker River USGS Gage at Byfield High Pulse Duration

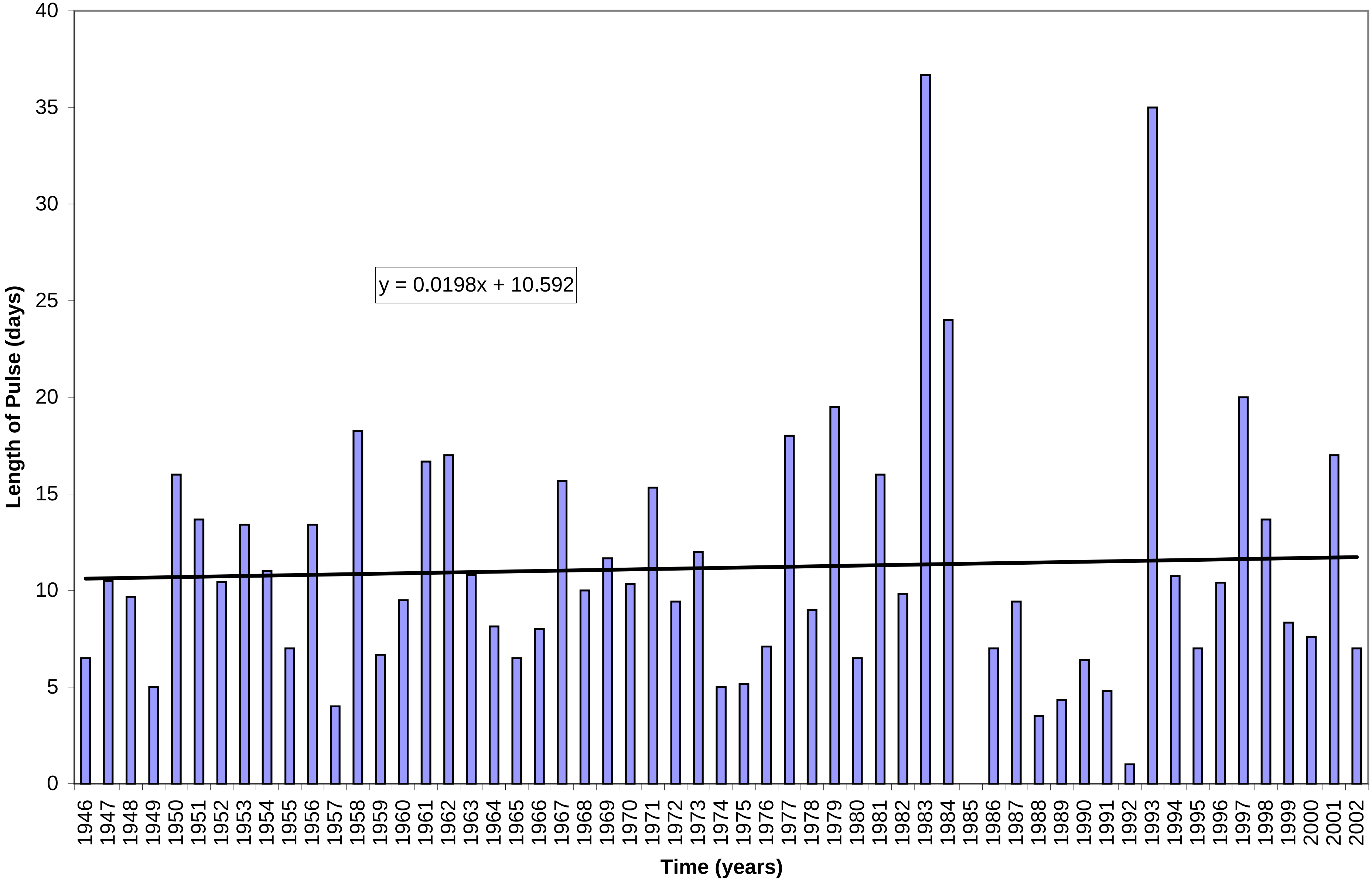


Figure A-30: Parker River USGS Gage at Byfield Rise Rate

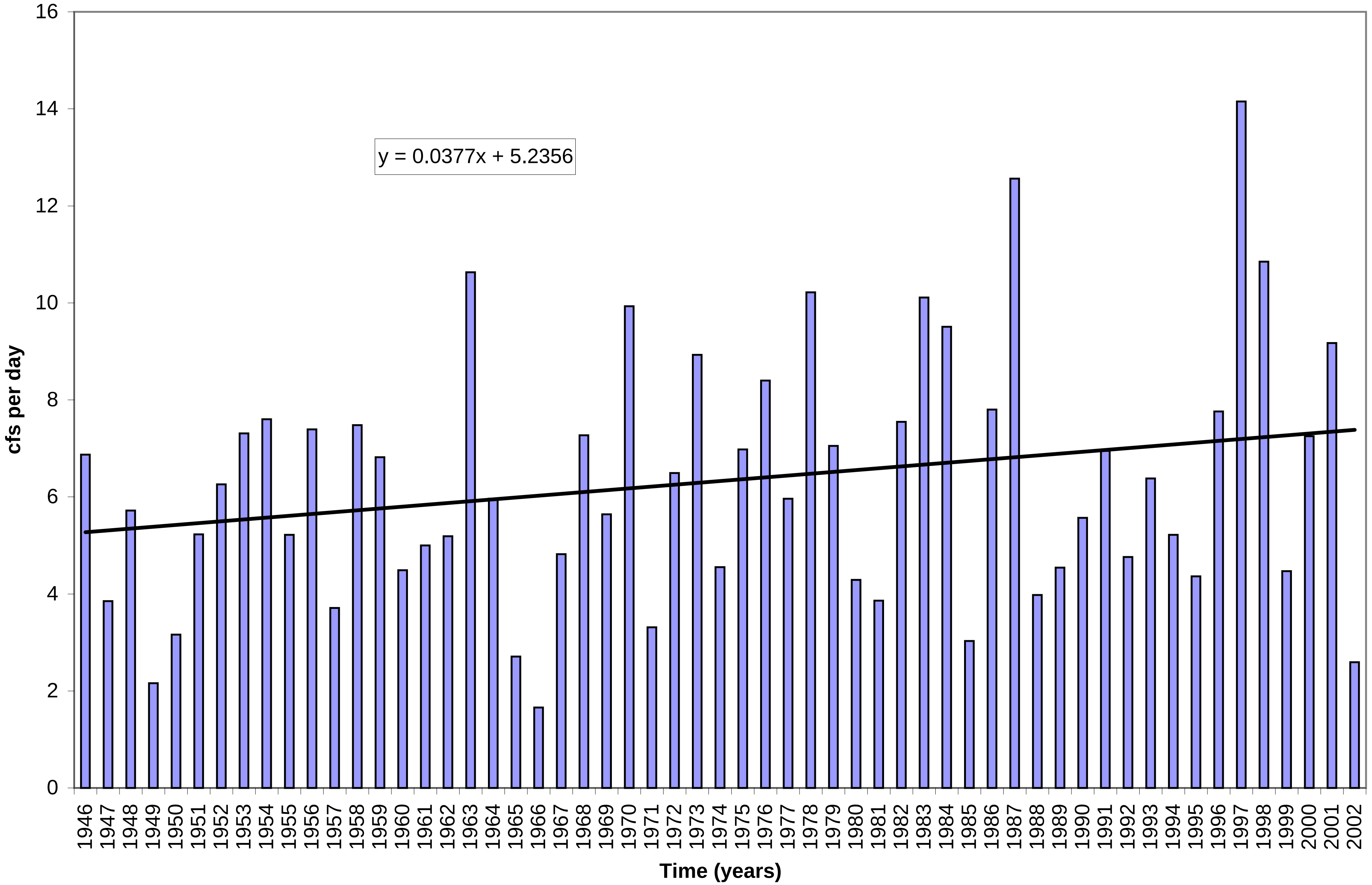


Figure A-31: Parker River USGS Gage at Byfield Fall Rate

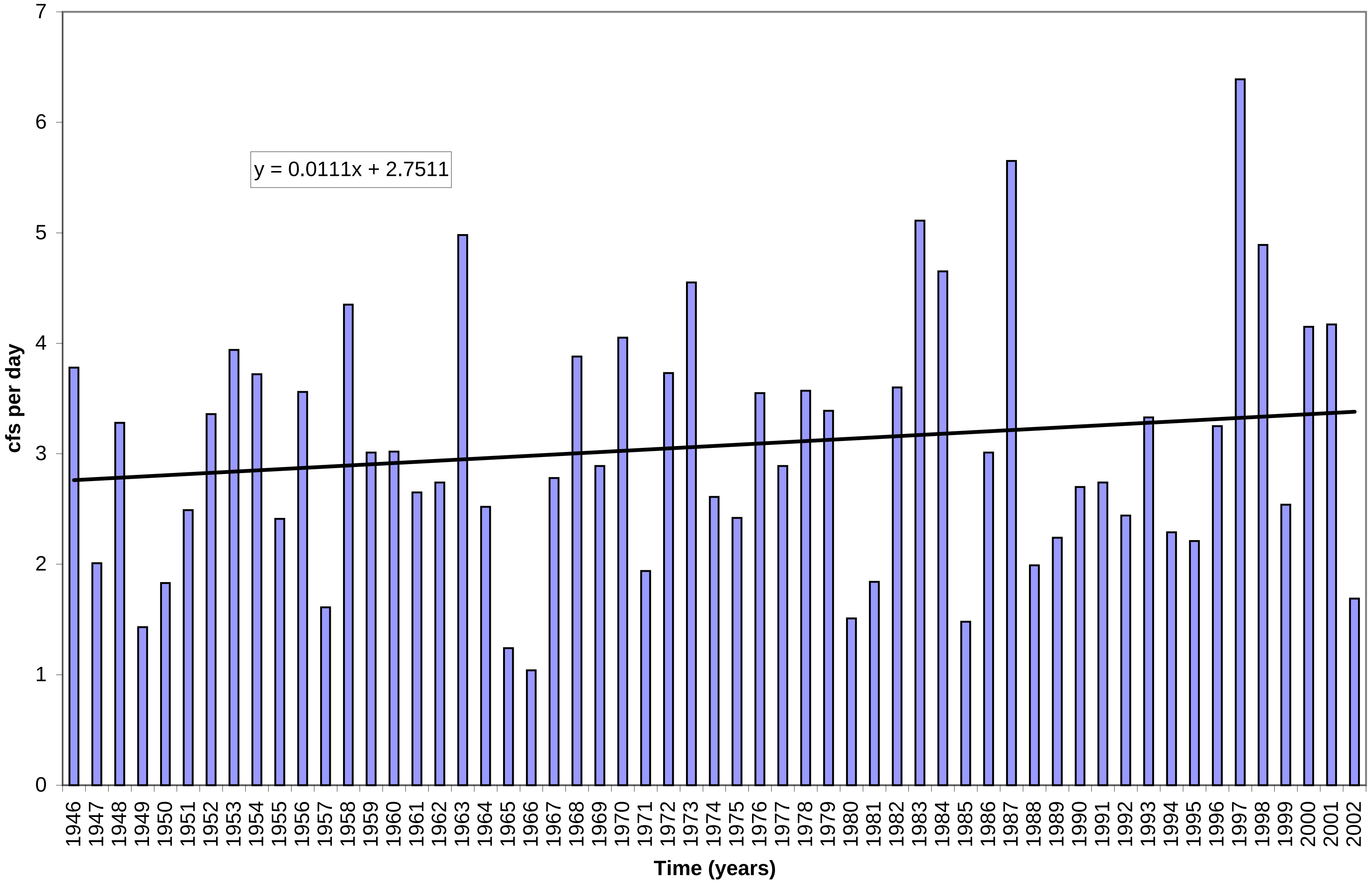
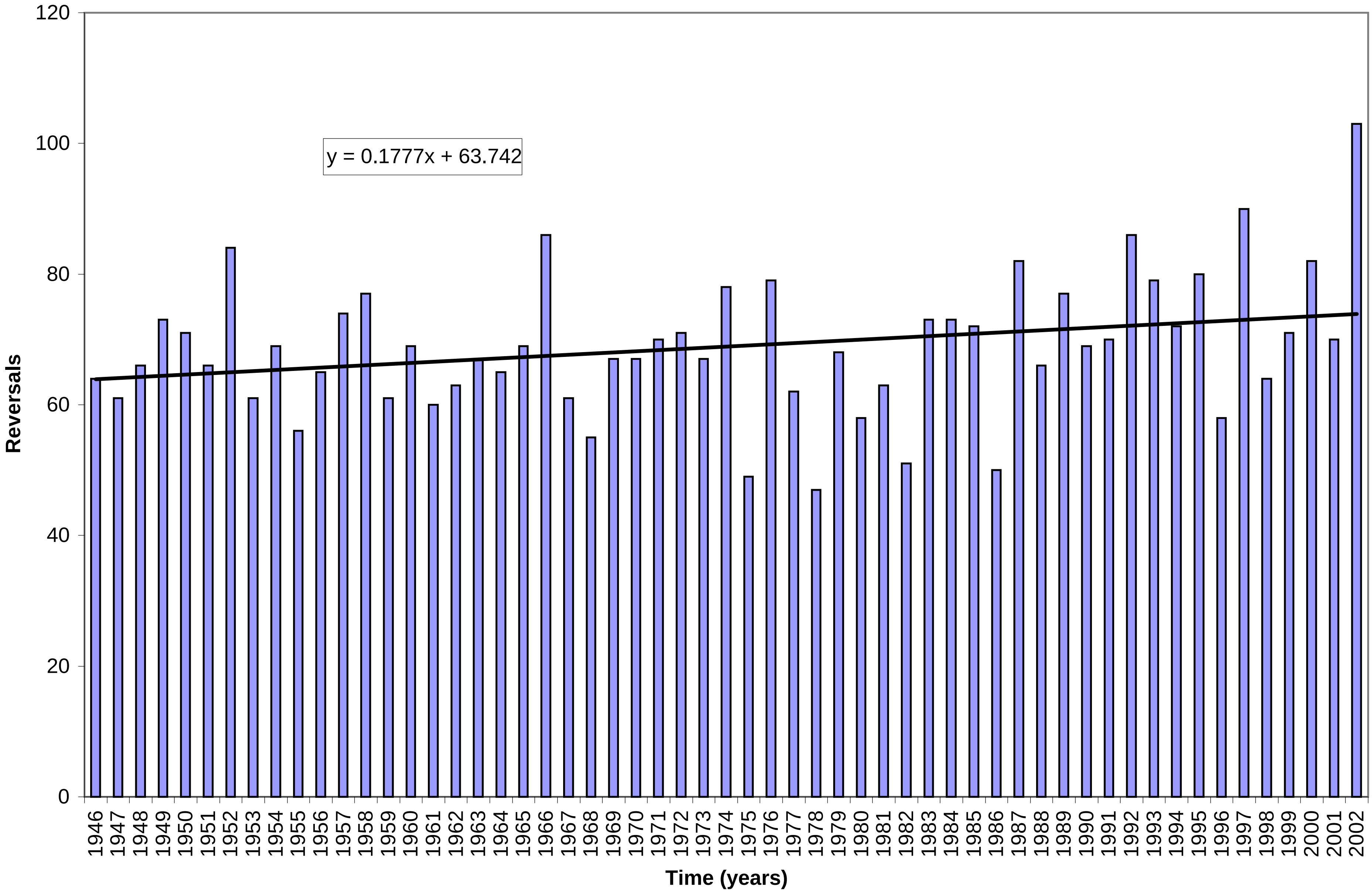


Figure A-32: Parker River USGS Gage at Byfield Number of Reversals



Appendix B-Graphs from the Evaluation of Pre- and Post-Impact Analysis at the Byfield USGS Gage (IHA Analysis)

Figure B-1: Parker River USGS Gage at Byfield Average Monthly Flow for January (Pre and Post Impact Assessment)

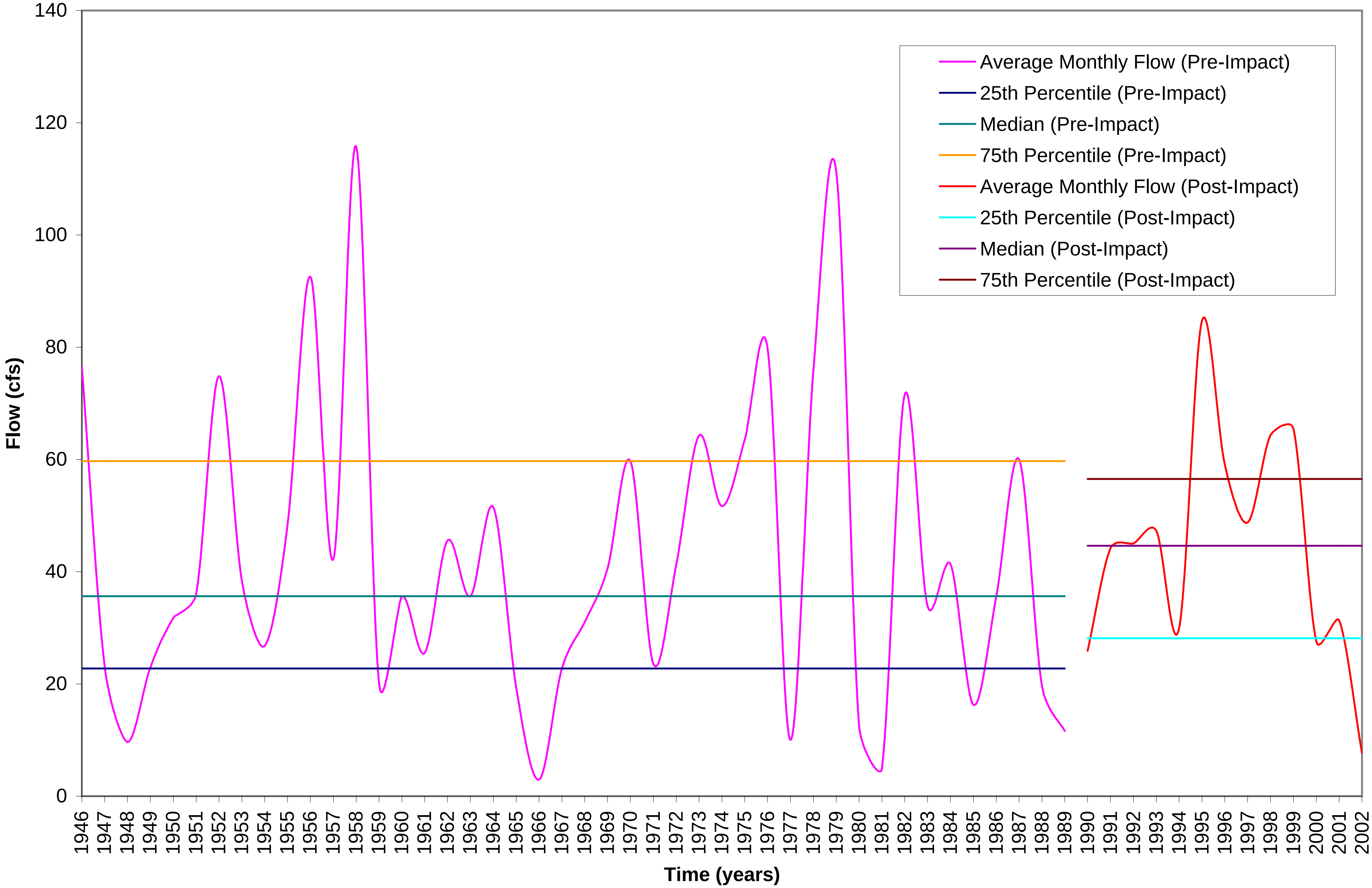


Figure B-2: Parker River USGS Gage at Byfield Average Monthly Flow for February (Pre and Post Impact Assessment)

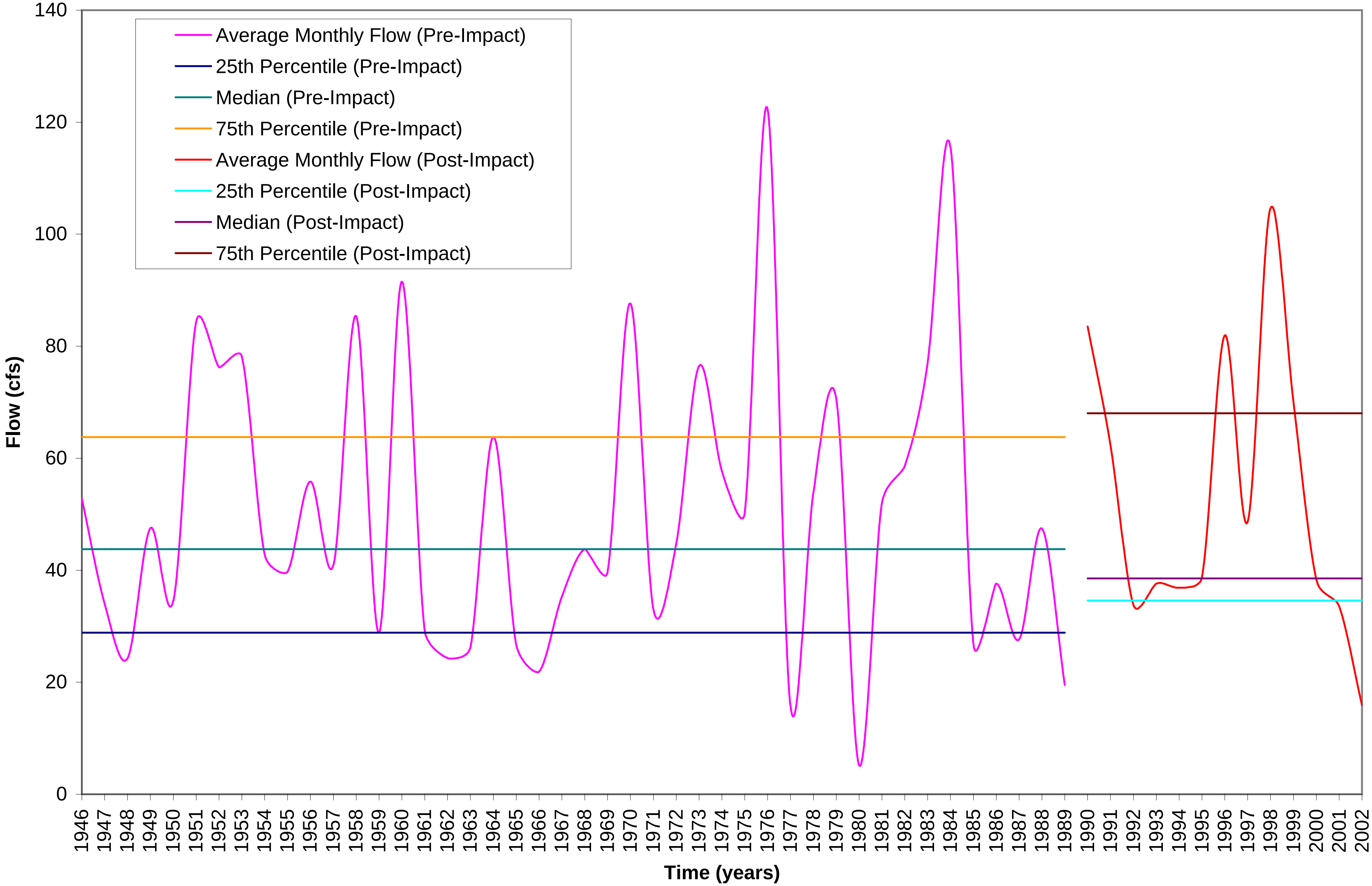


Figure B-3: Parker River USGS Gage at Byfield Average Monthly Flow for March (Pre and Post Impact Assessment)

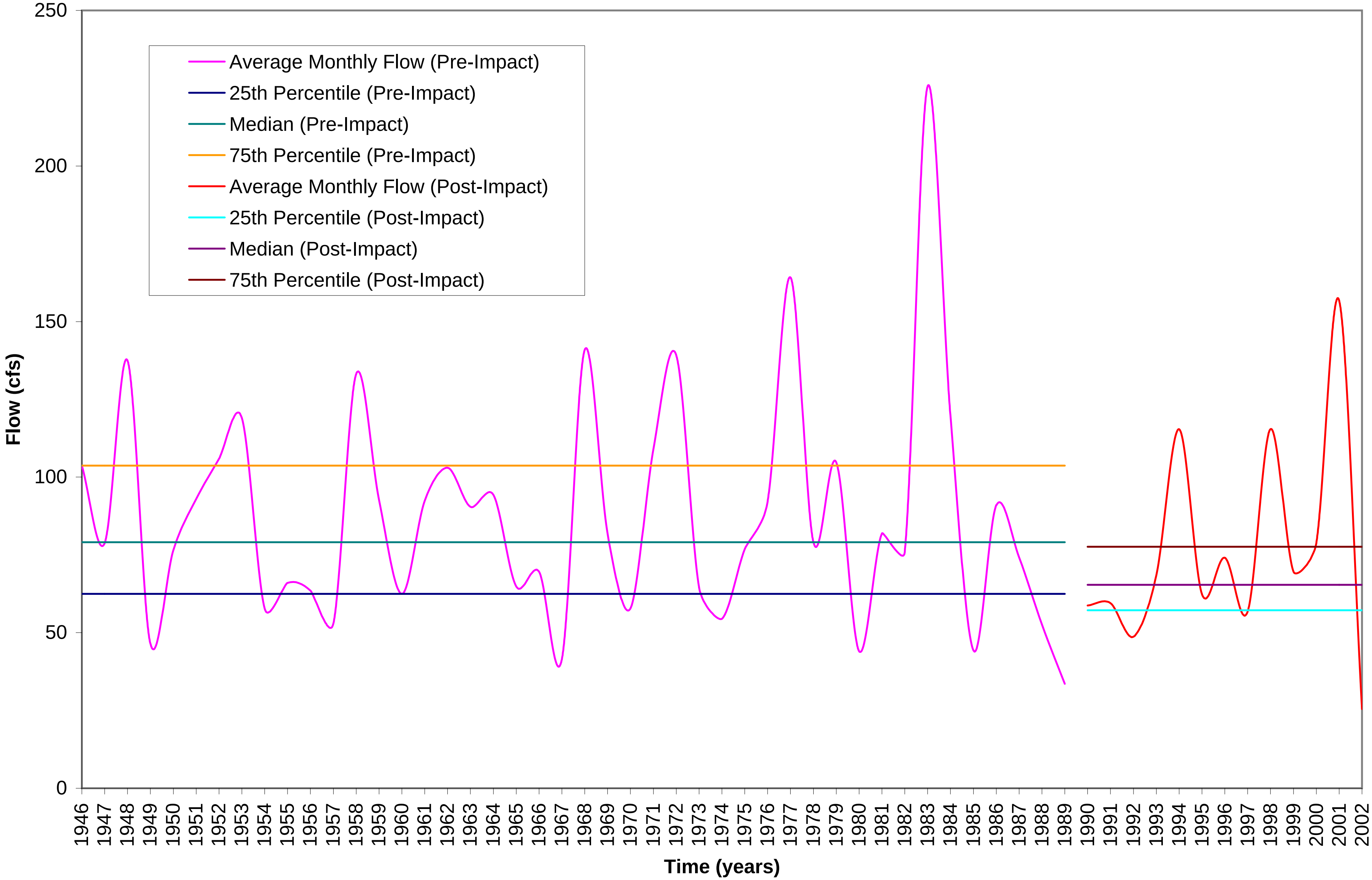


Figure B-4: Parker River USGS Gage at Byfield Average Monthly Flow for April (Pre and Post Impact Assessment)

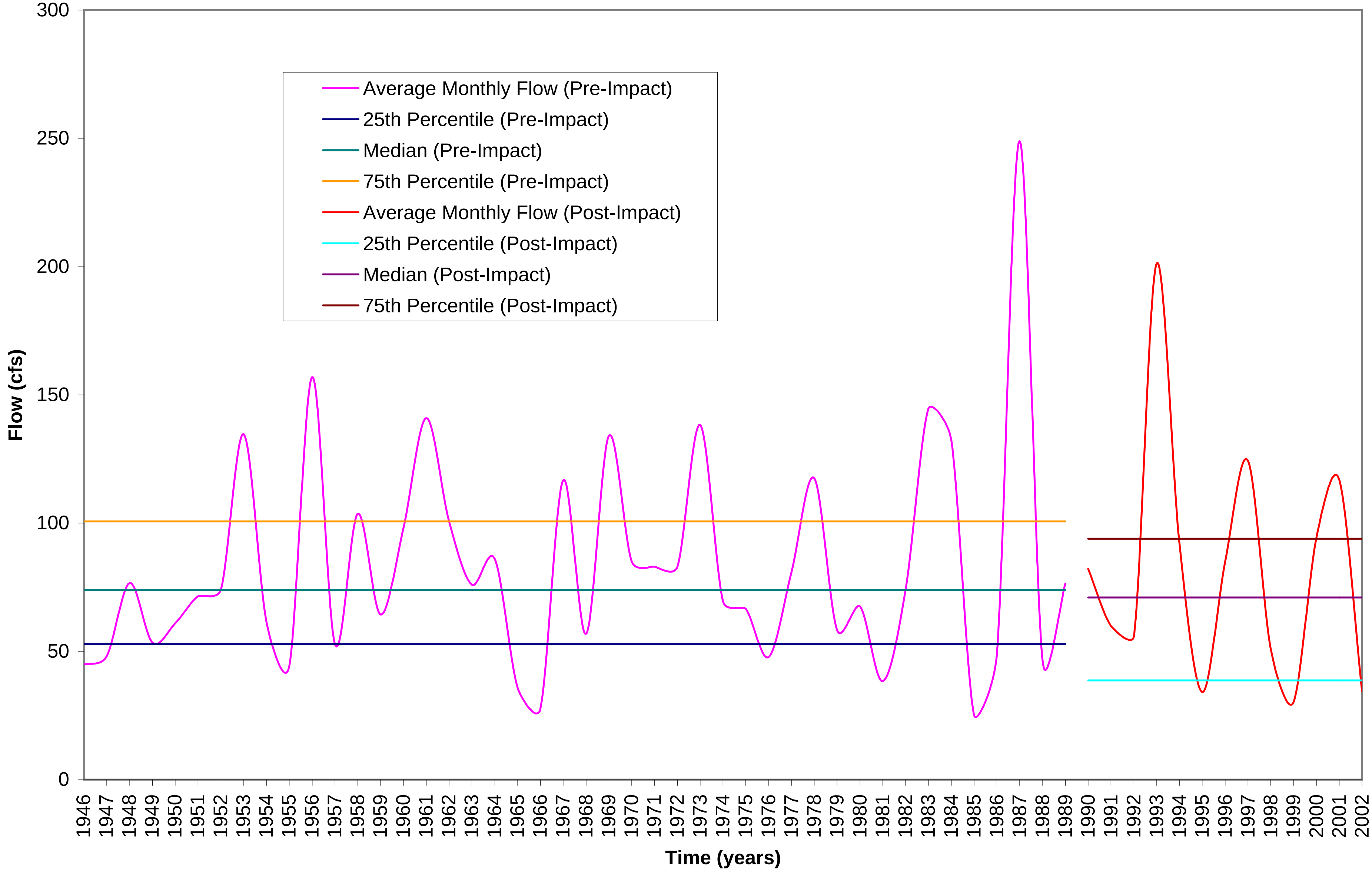


Figure B-5: Parker River USGS Gage at Byfield Average Monthly Flow for May (Pre and Post Impact Assessment)

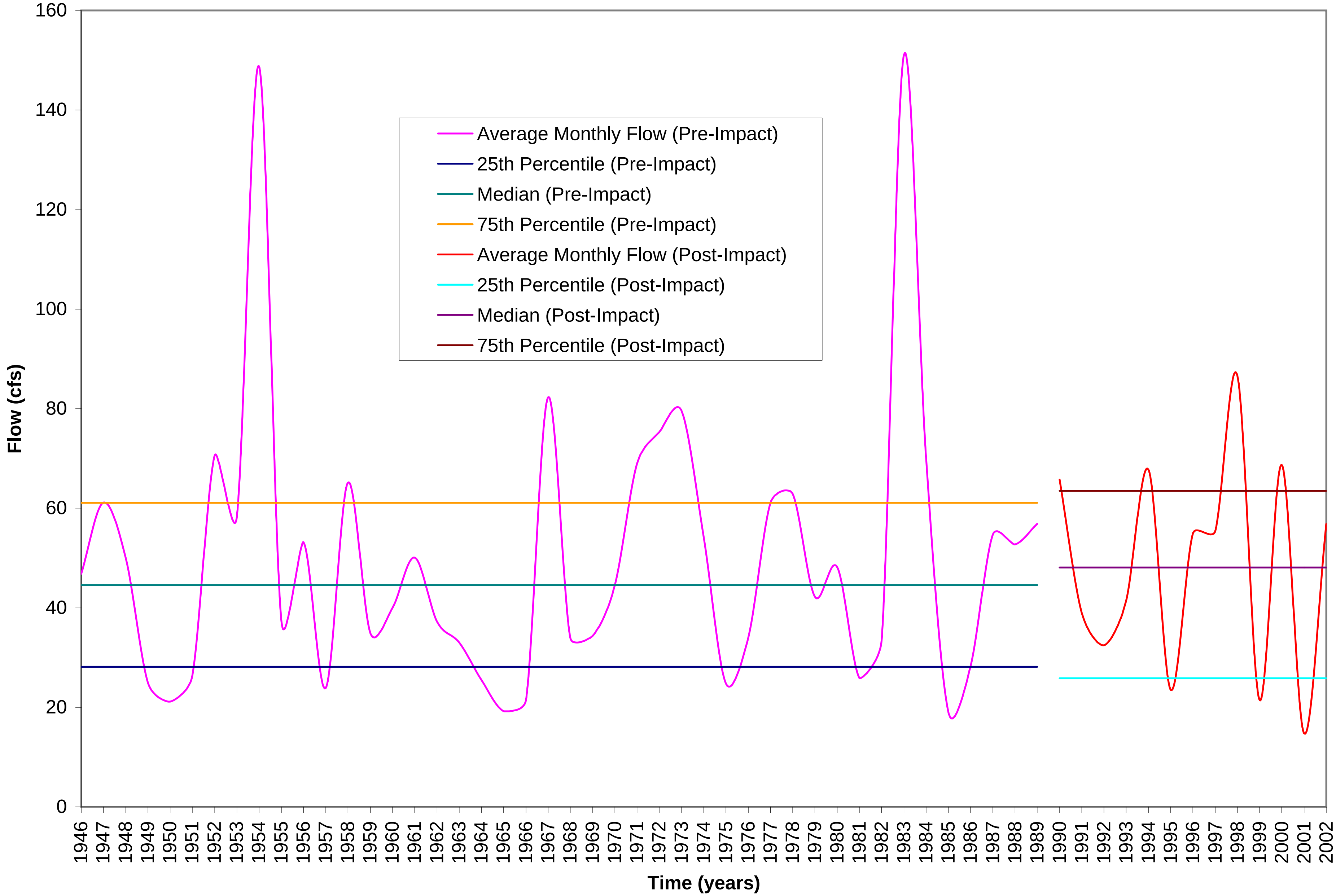


Figure B-6: Parker River USGS Gage at Byfield Average Monthly Flow for June (Pre and Post Impact Assessment)

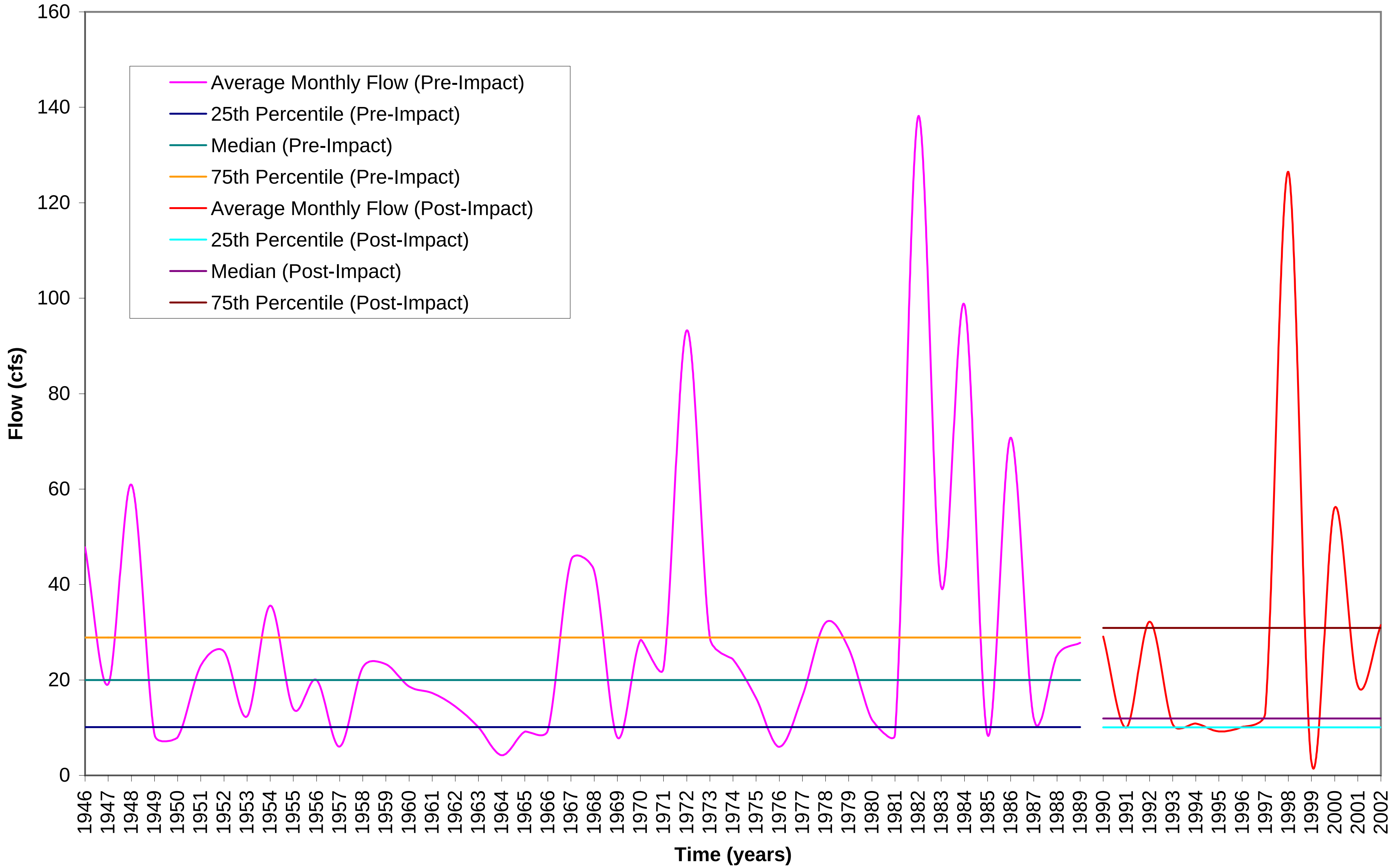


Figure B-7: Parker River USGS Gage at Byfield Average Monthly Flow for July (Pre and Post Impact Assessment)

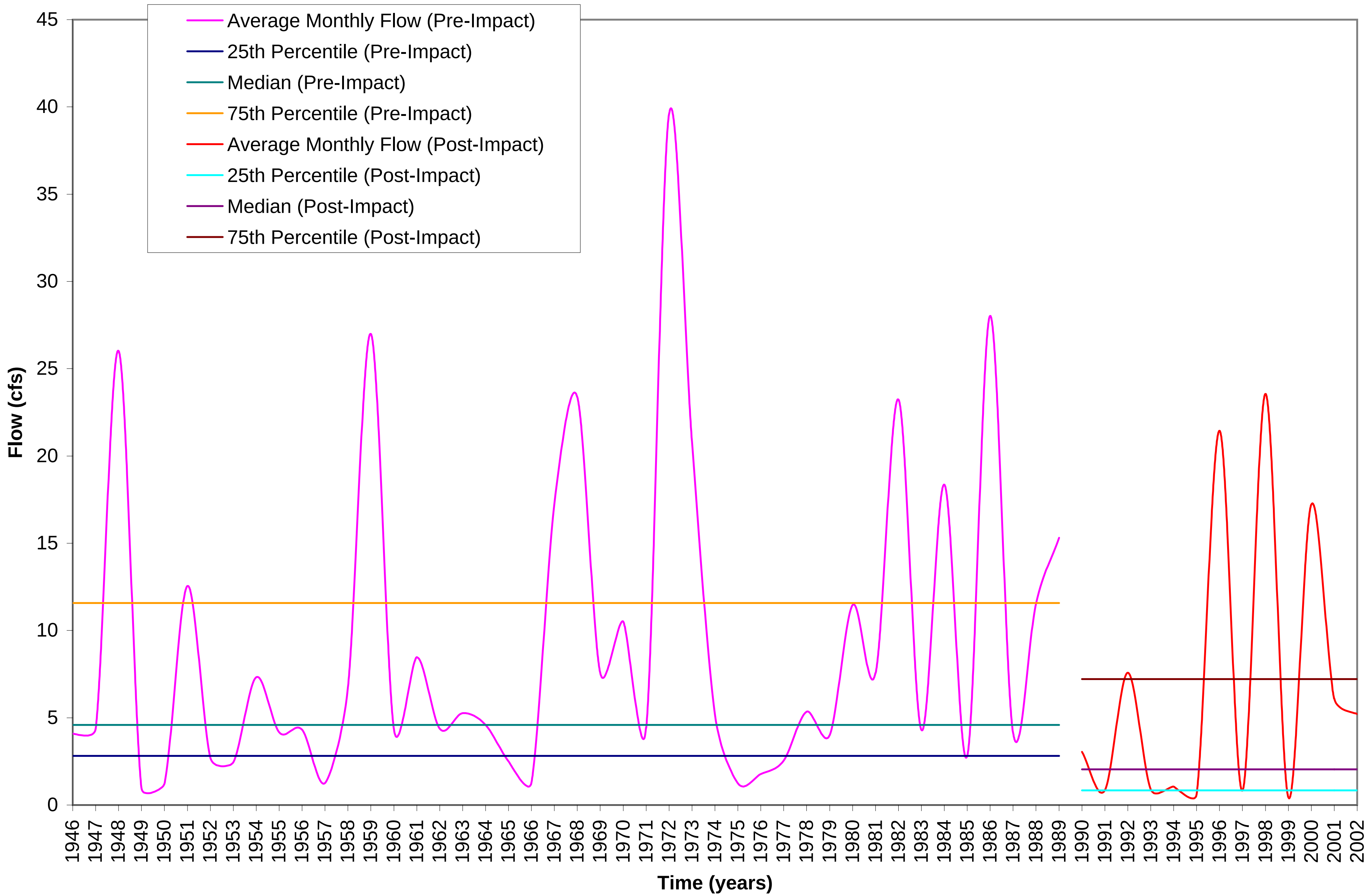


Figure B-8: Parker River USGS Gage at Byfield Average Monthly Flow for August (Pre and Post Impact Assessment)

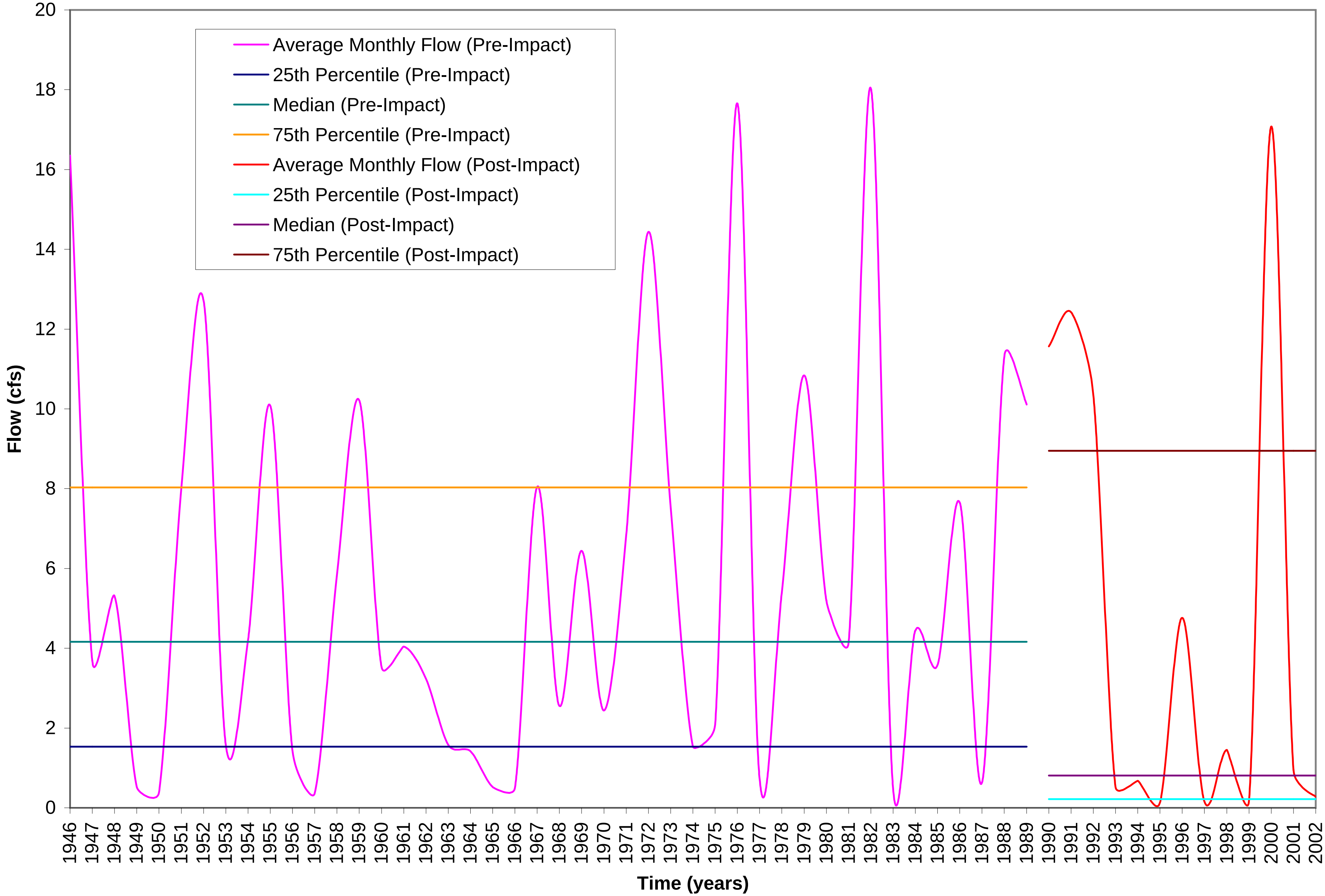


Figure B-9: Parker River USGS Gage at Byfield Average Monthly Flow for September (Pre and Post Impact Assessment)

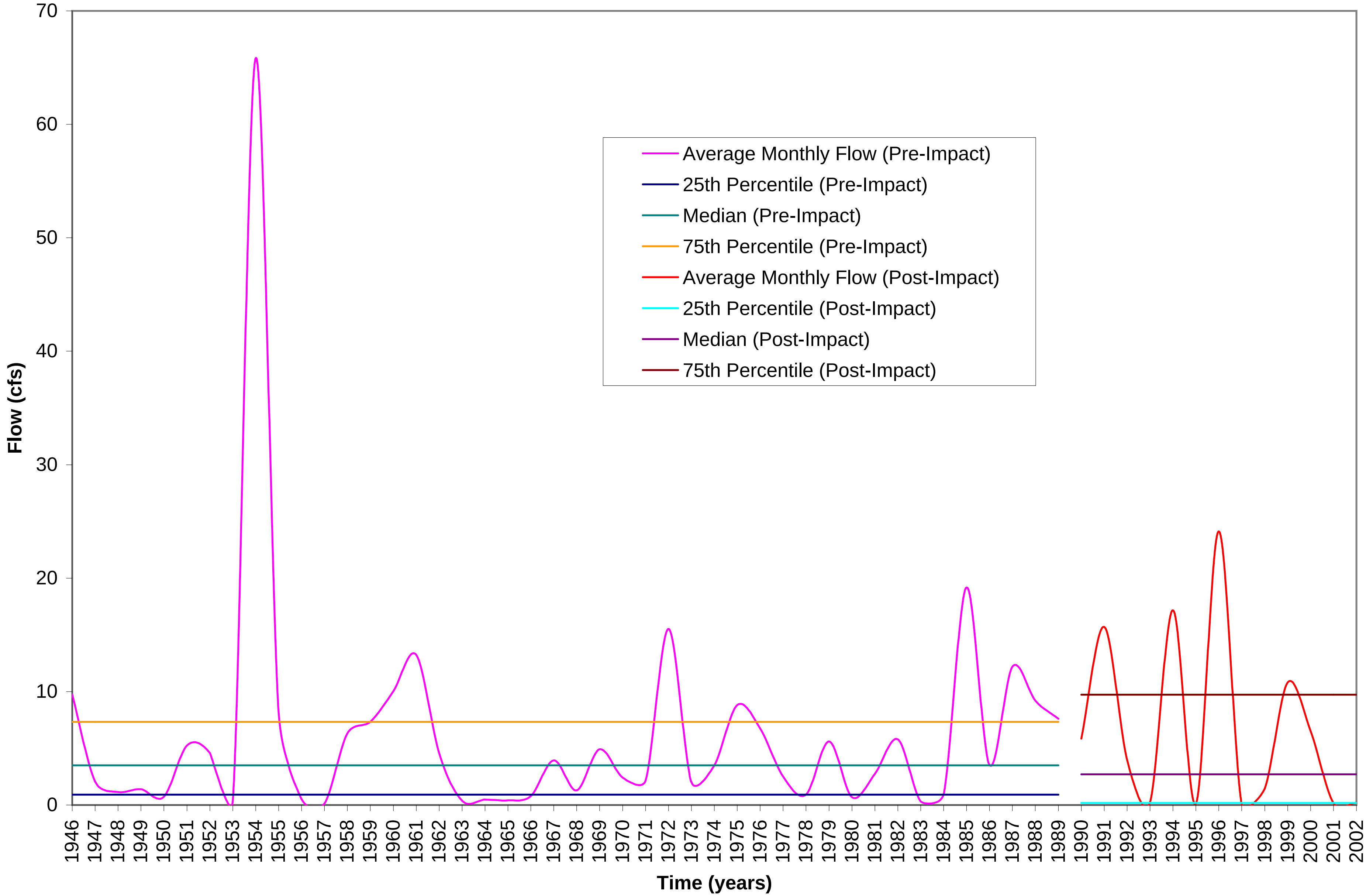


Figure B-10: Parker River USGS Gage at Byfield Average Monthly Flow for October (Pre and Post Impact Assessment)

Figure B-11: Parker River USGS Gage at Byfield Average Monthly Flow for November (Pre and Post Impact Assessment)

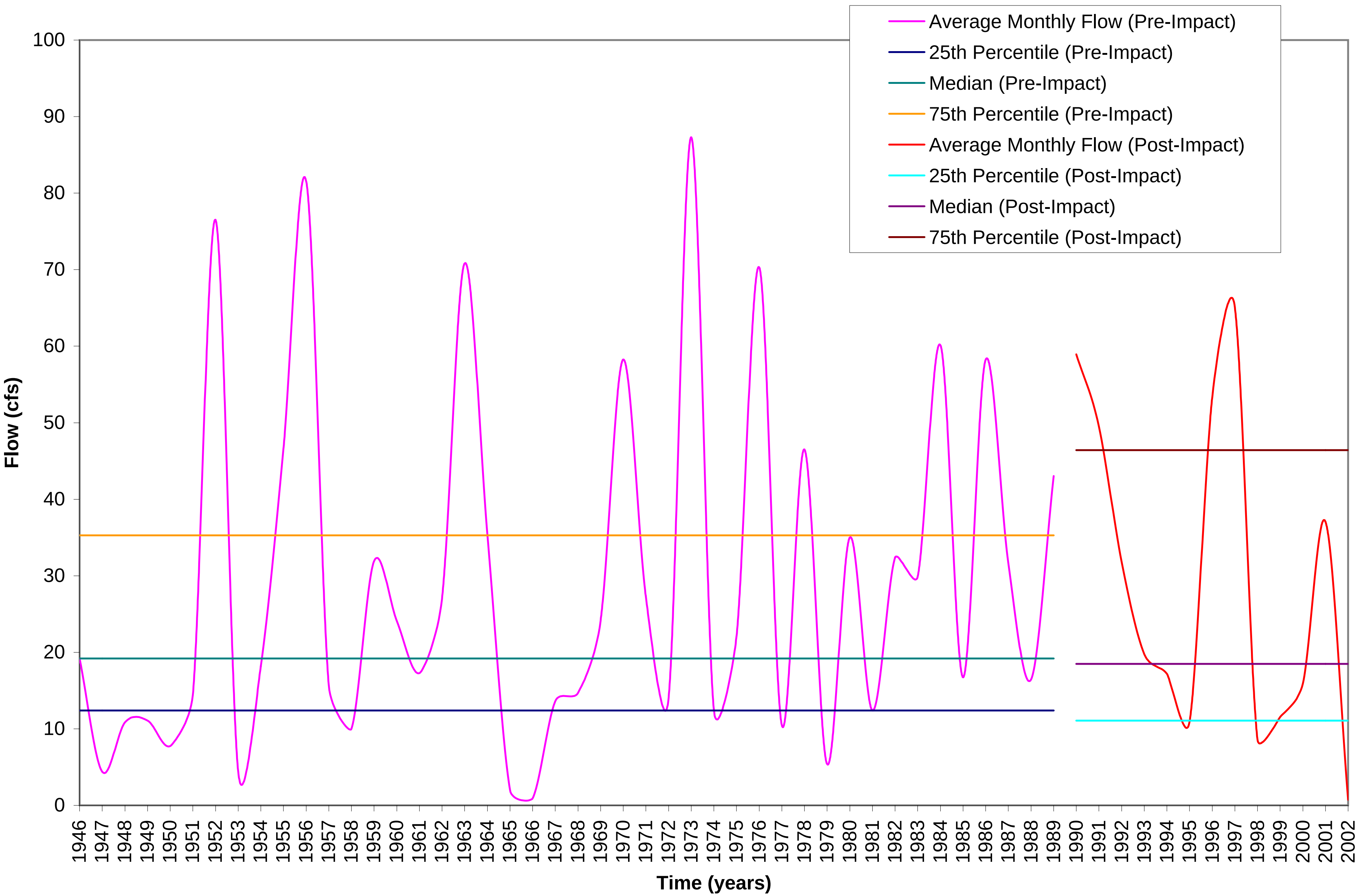
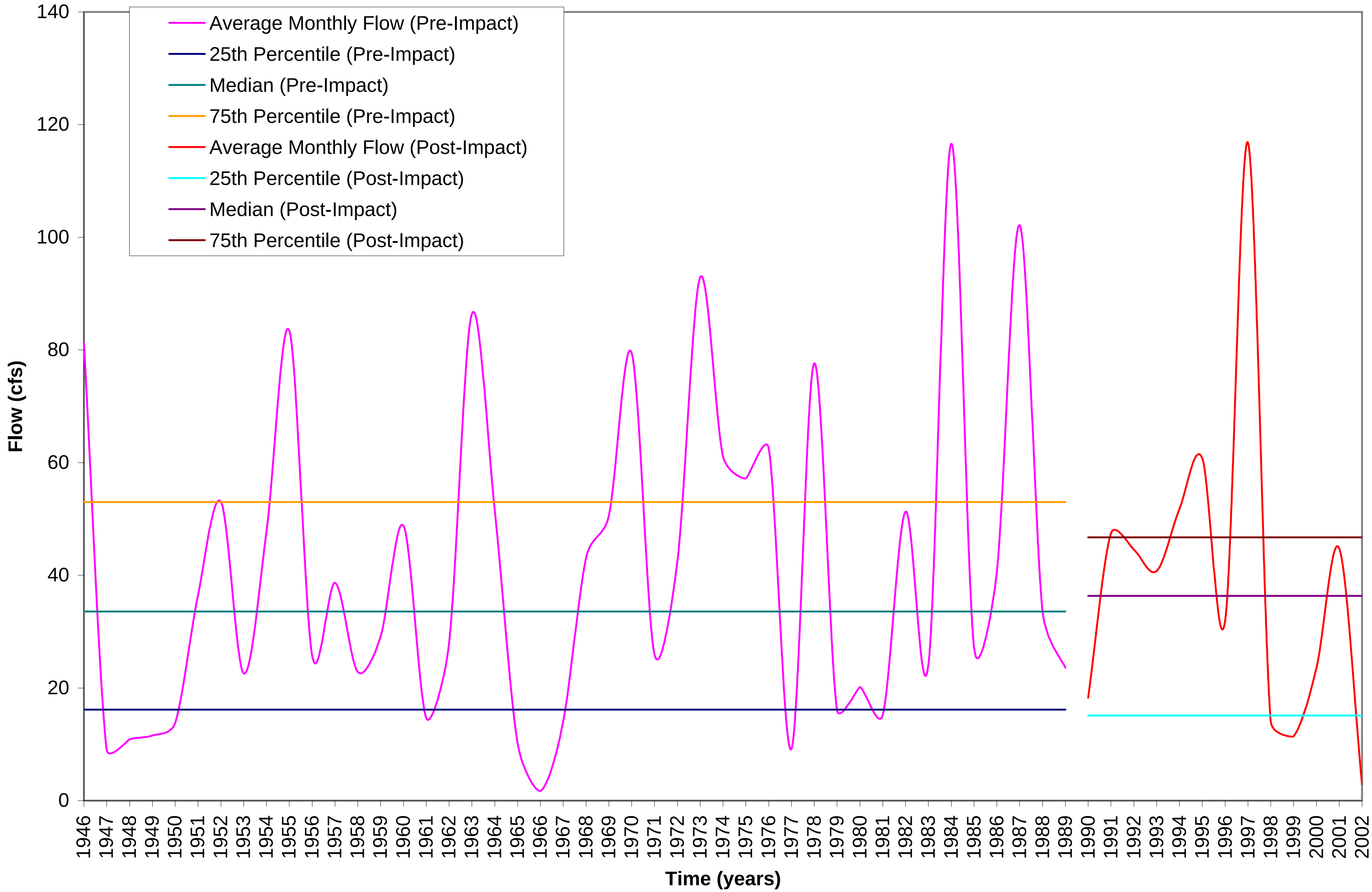


Figure B-12: Parker River USGS Gage at Byfield Average Monthly Flow for December (Pre and Post Impact Assessment)



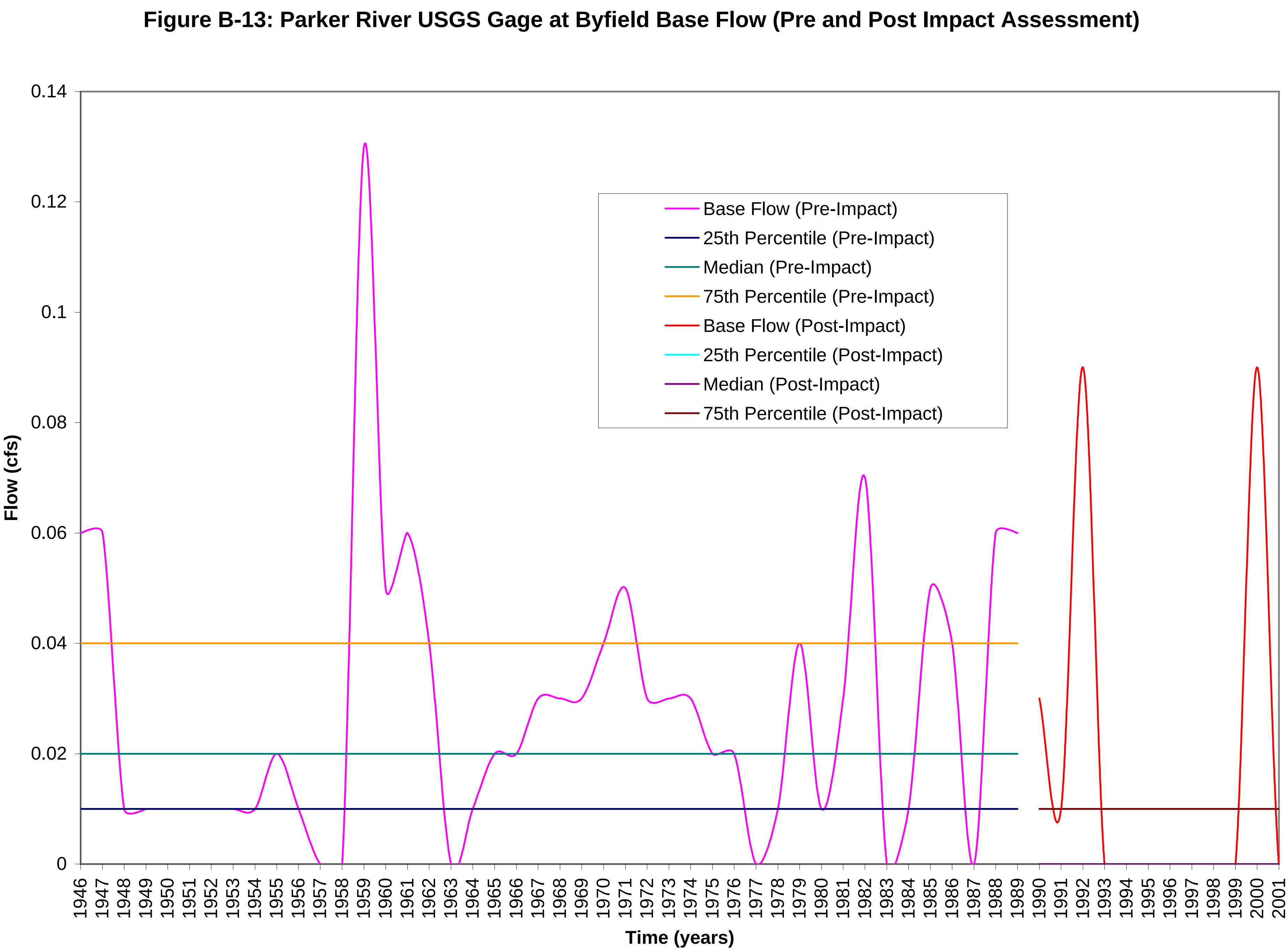


Figure B-13: Parker River USGS Gage at Byfield Base Flow (Pre and Post Impact Assessment)
Flow (cfs)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time (years)
1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
Base Flow (Pre-Impact)
25th Percentile (Pre-Impact)
Median (Pre-Impact)
75th Percentile (Pre-Impact)
Base Flow (Post-Impact)
25th Percentile (Post-Impact)
Median (Post-Impact)
75th Percentile (Post-Impact)

Figure B-14: Parker River USGS Gage at Byfield 1-Day Average Minimum Flow (Pre and Post Impact Assessment)

Figure B-15: Parker River USGS Gage at Byfield 3-Day Average Minimum Flow (Pre and Post Impact Assessment)

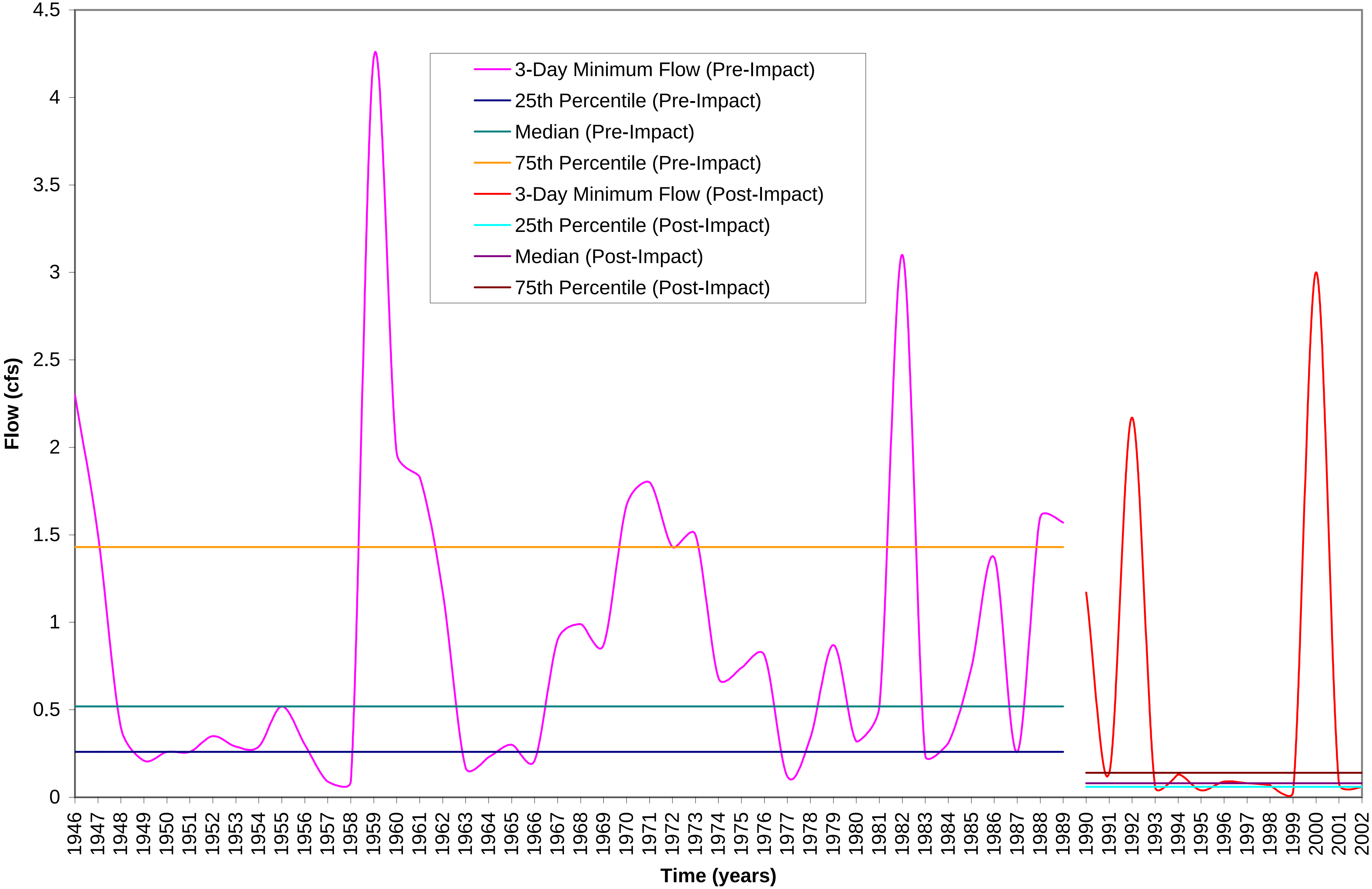


Figure B-16: Parker River USGS Gage at Byfield 7-Day Average Minimum Flow (Pre and Post Impact Assessment)

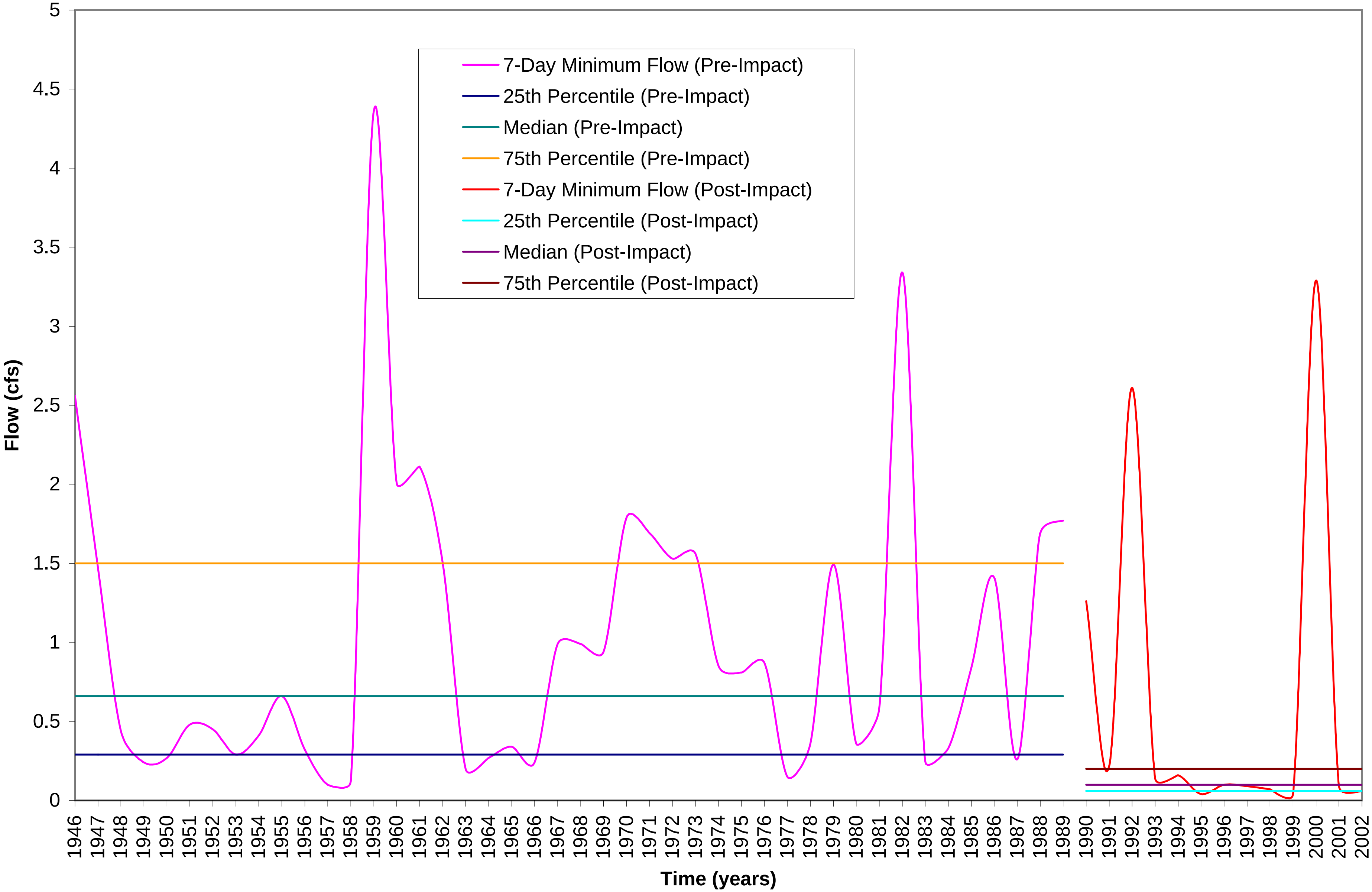


Figure B-17: Parker River USGS Gage at Byfield 30-Day Average Minimum Flow (Pre and Post Impact Assessment)

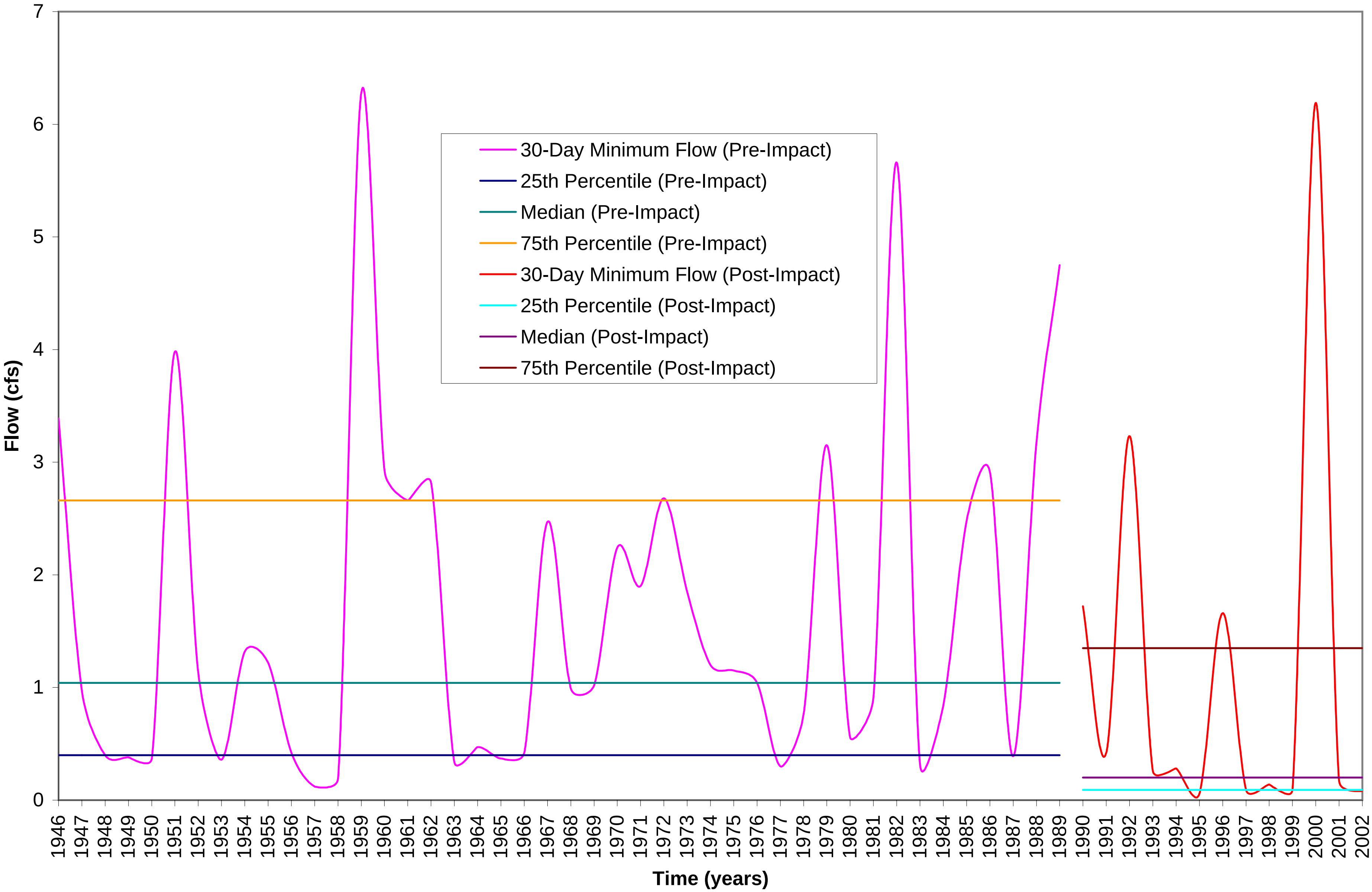


Figure B-18: Parker River USGS Gage at Byfield 90-Day Average Minimum Flow (Pre and Post Impact Assessment)

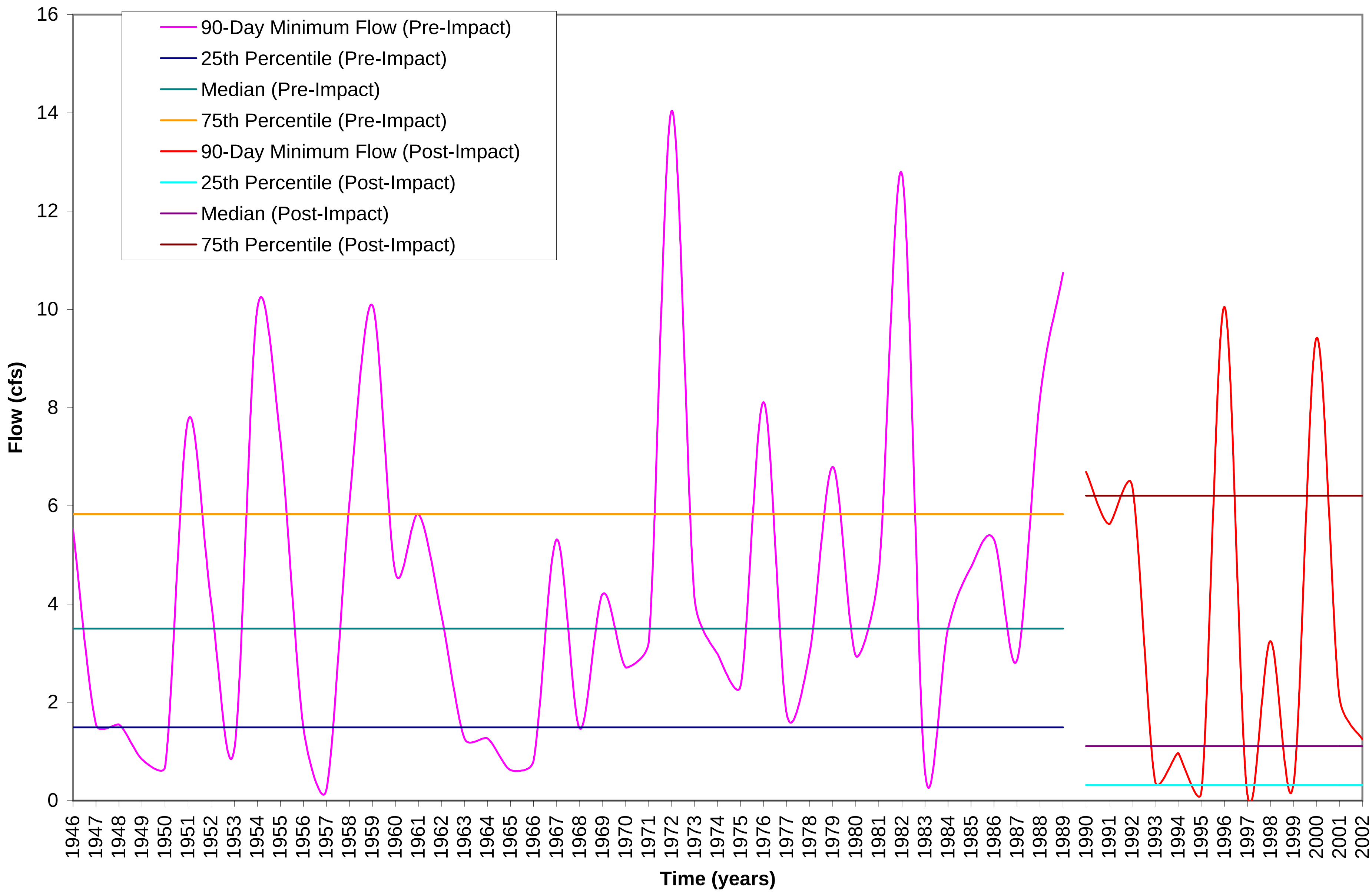


Figure B-19: Parker River USGS Gage at Byfield 1-Day Average Maximum Flow (Pre and Post Impact Assessment)

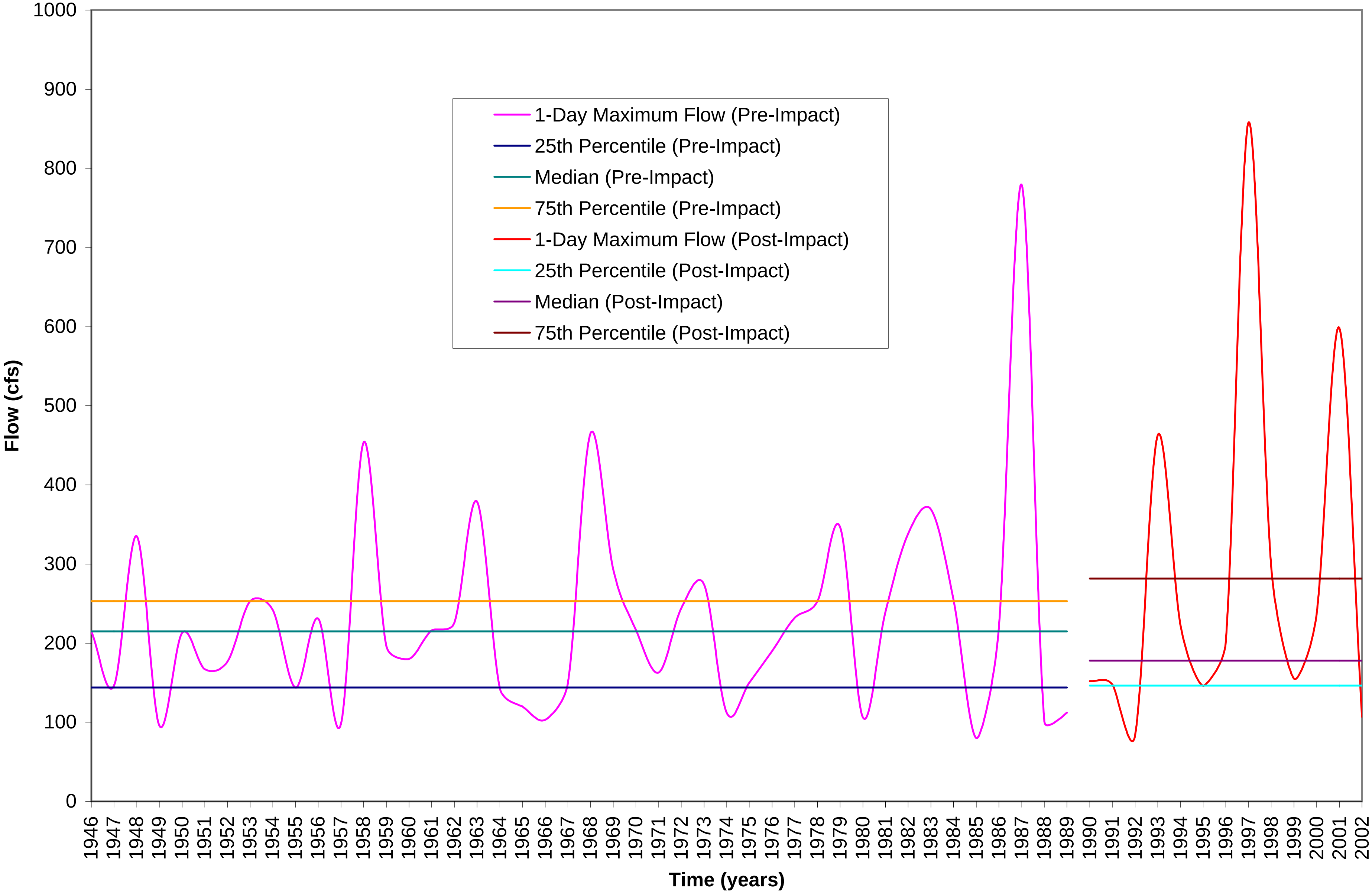


Figure B-20: Parker River USGS Gage at Byfield 3-Day Average Maximum Flow (Pre and Post Impact Assessment)

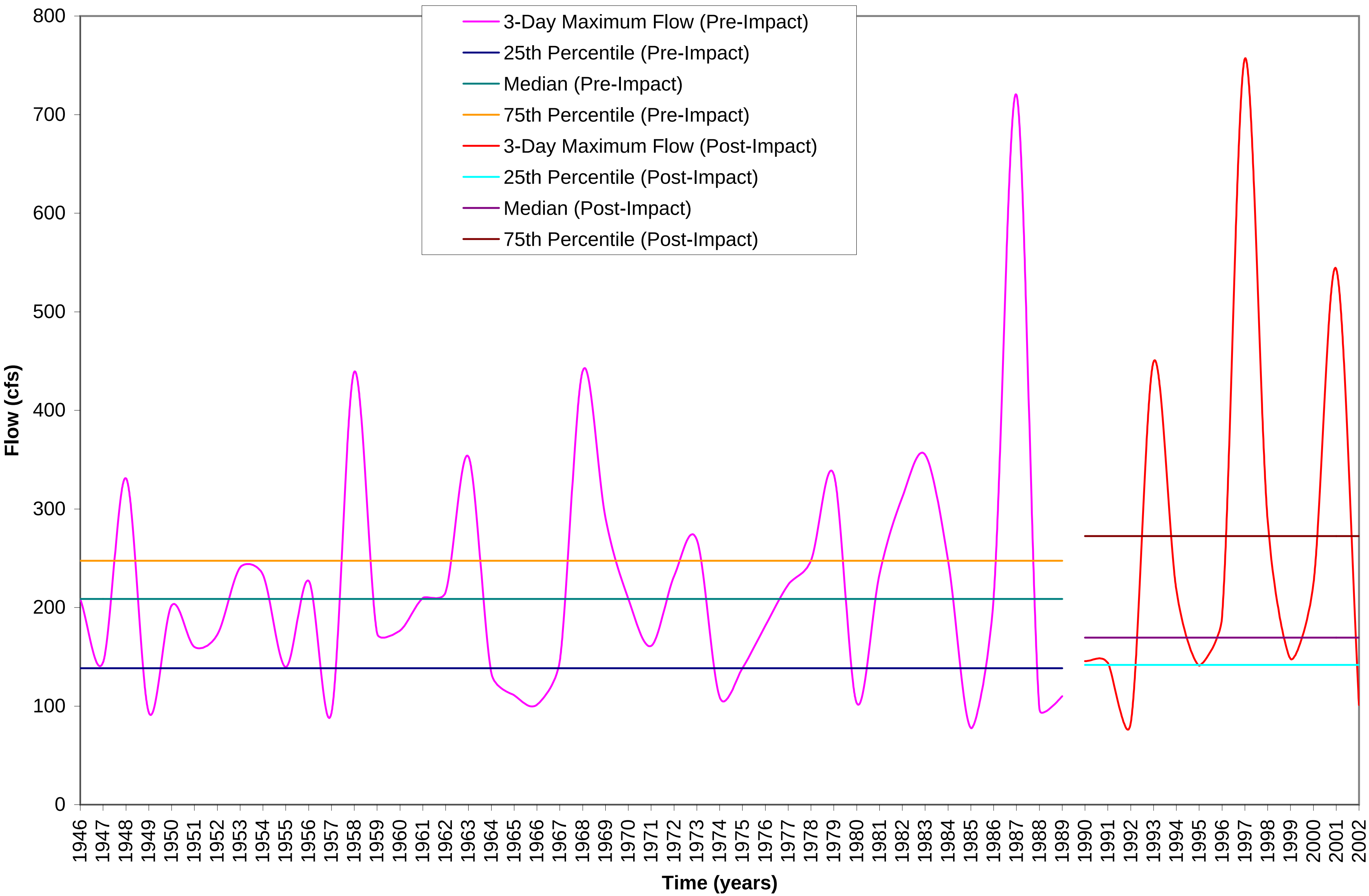


Figure B-21: Parker River USGS Gage at Byfield 7-Day Average Maximum Flow (Pre and Post Impact Assessment)

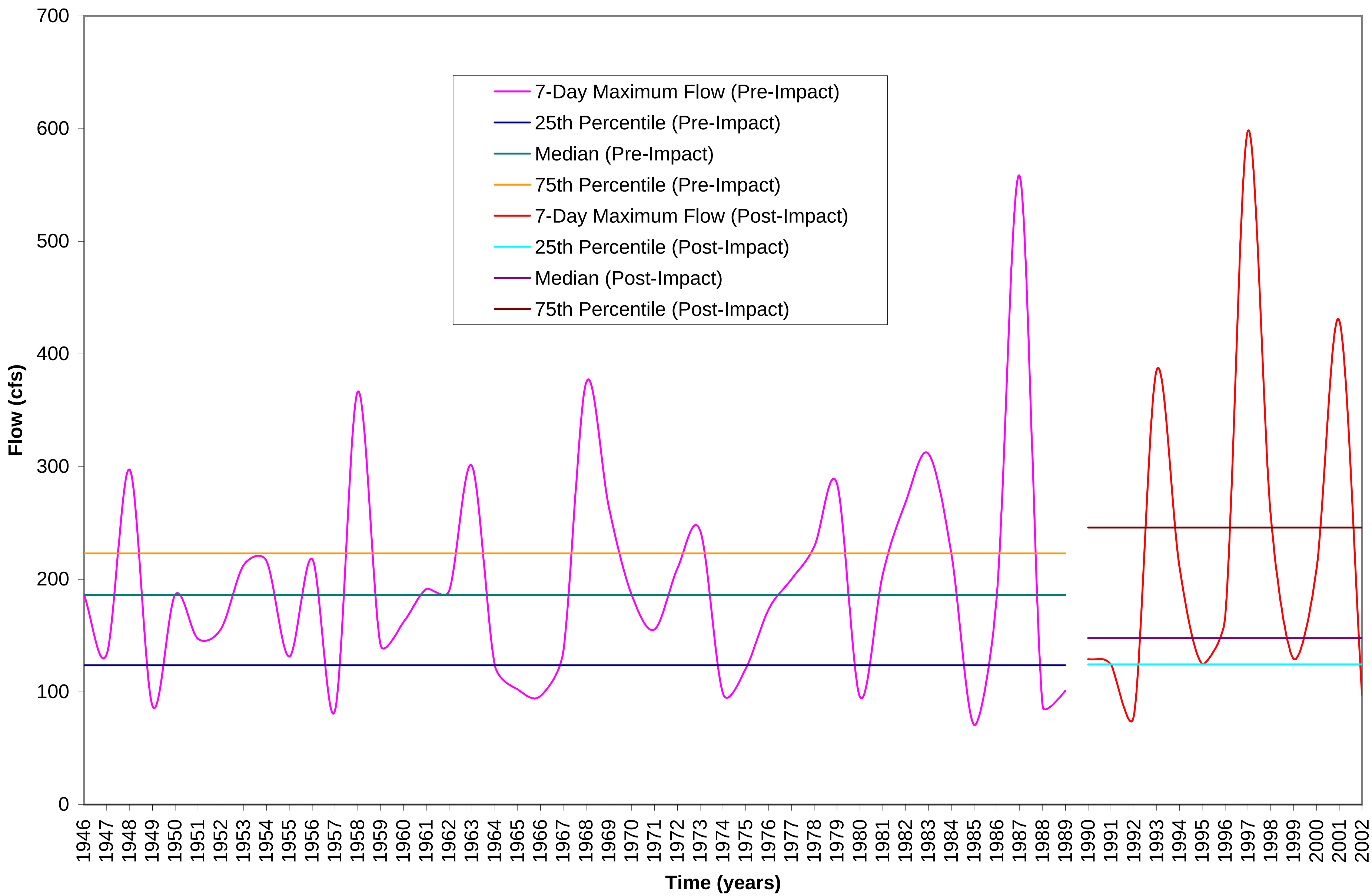


Figure B-22: Parker River USGS Gage at Byfield 30-Day Average Maximum Flow (Pre and Post Impact Assessment)

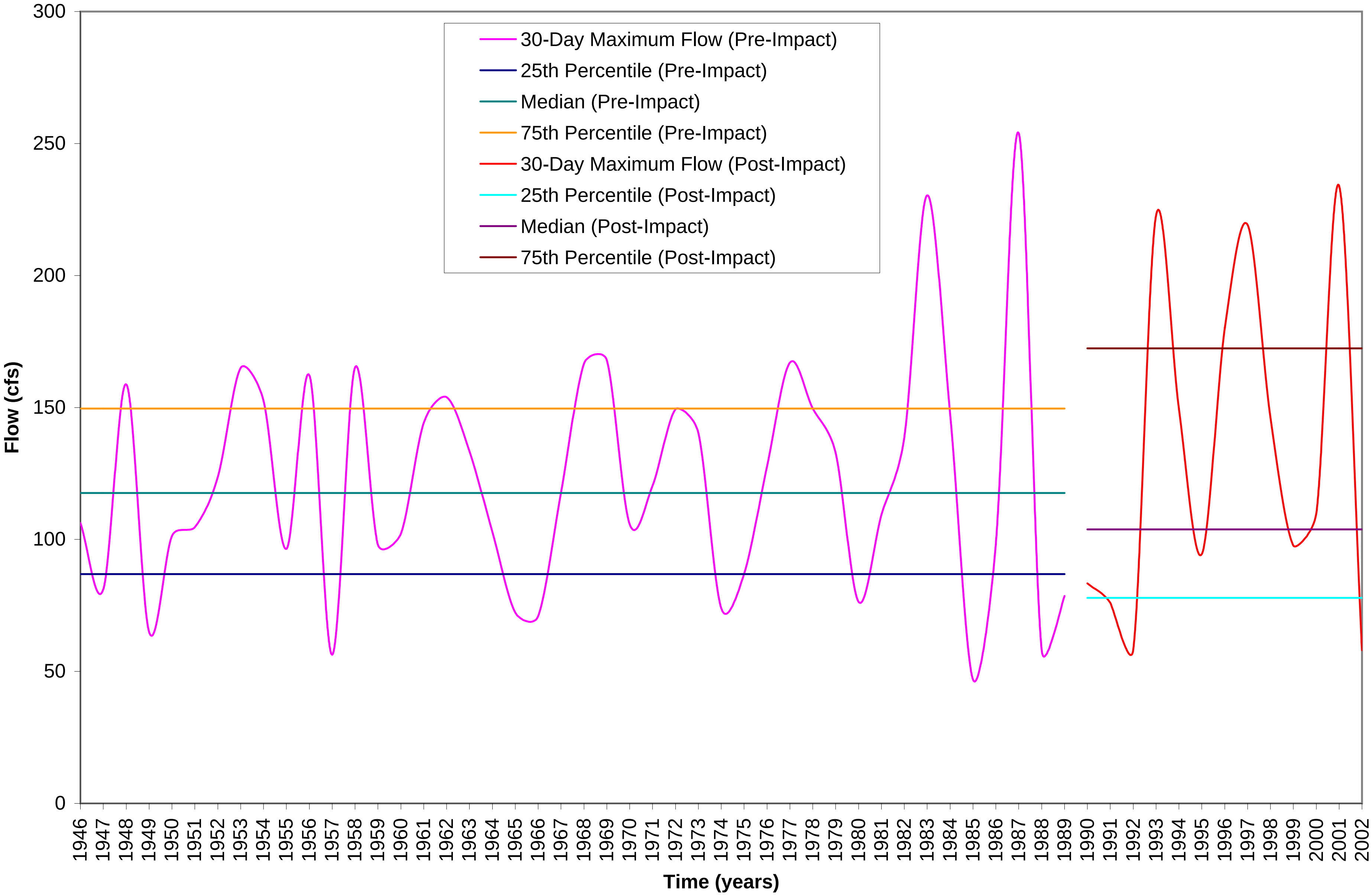


Figure B-23: Parker River USGS Gage at Byfield 90-Day Average Maximum Flow (Pre and Post Impact Assessment)

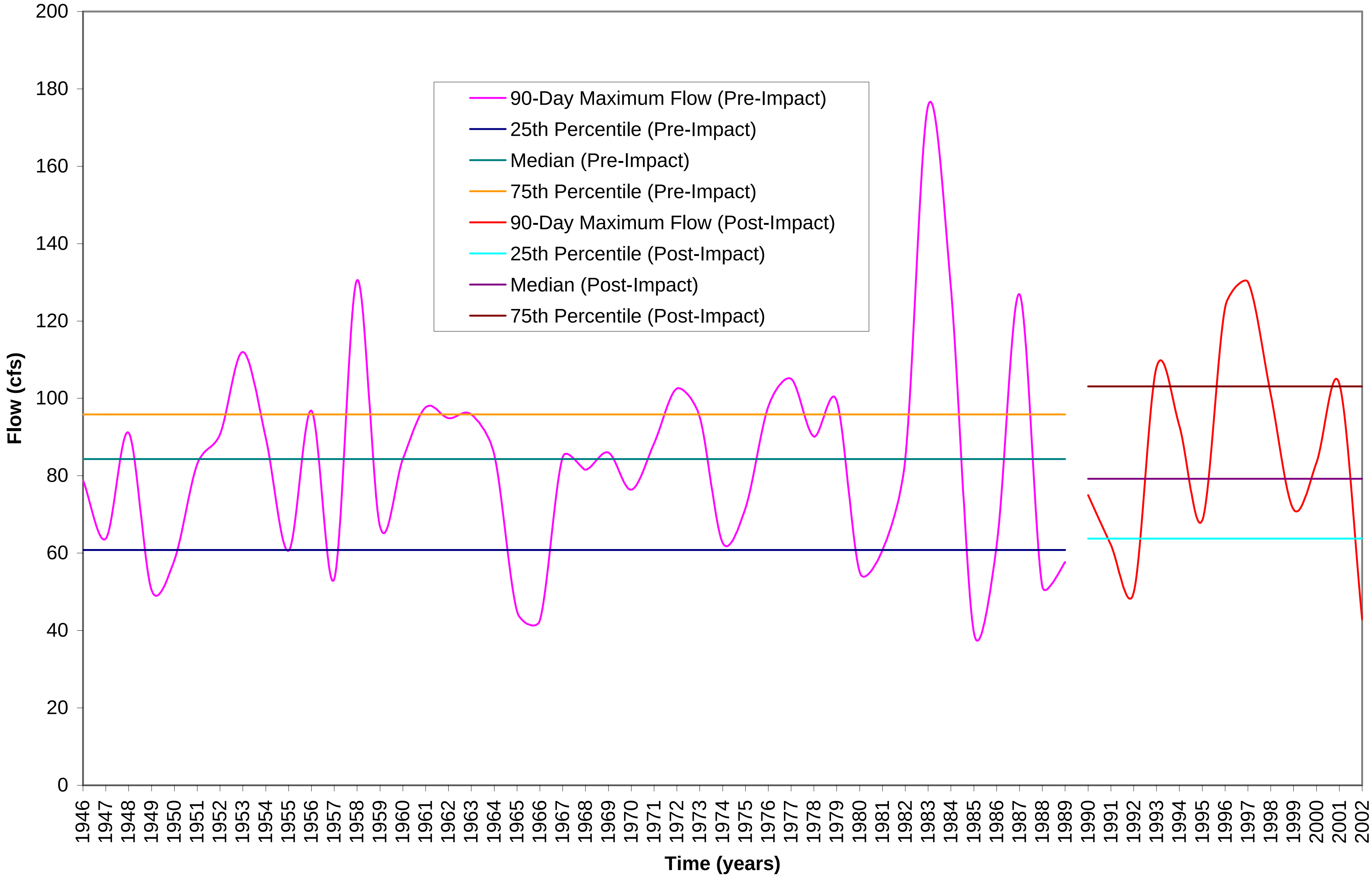


Figure B-24: Parker River USGS Gage at Byfield Julian Date of Annual 1-Day Maximum Flow (Pre and Post Impact Assessment)

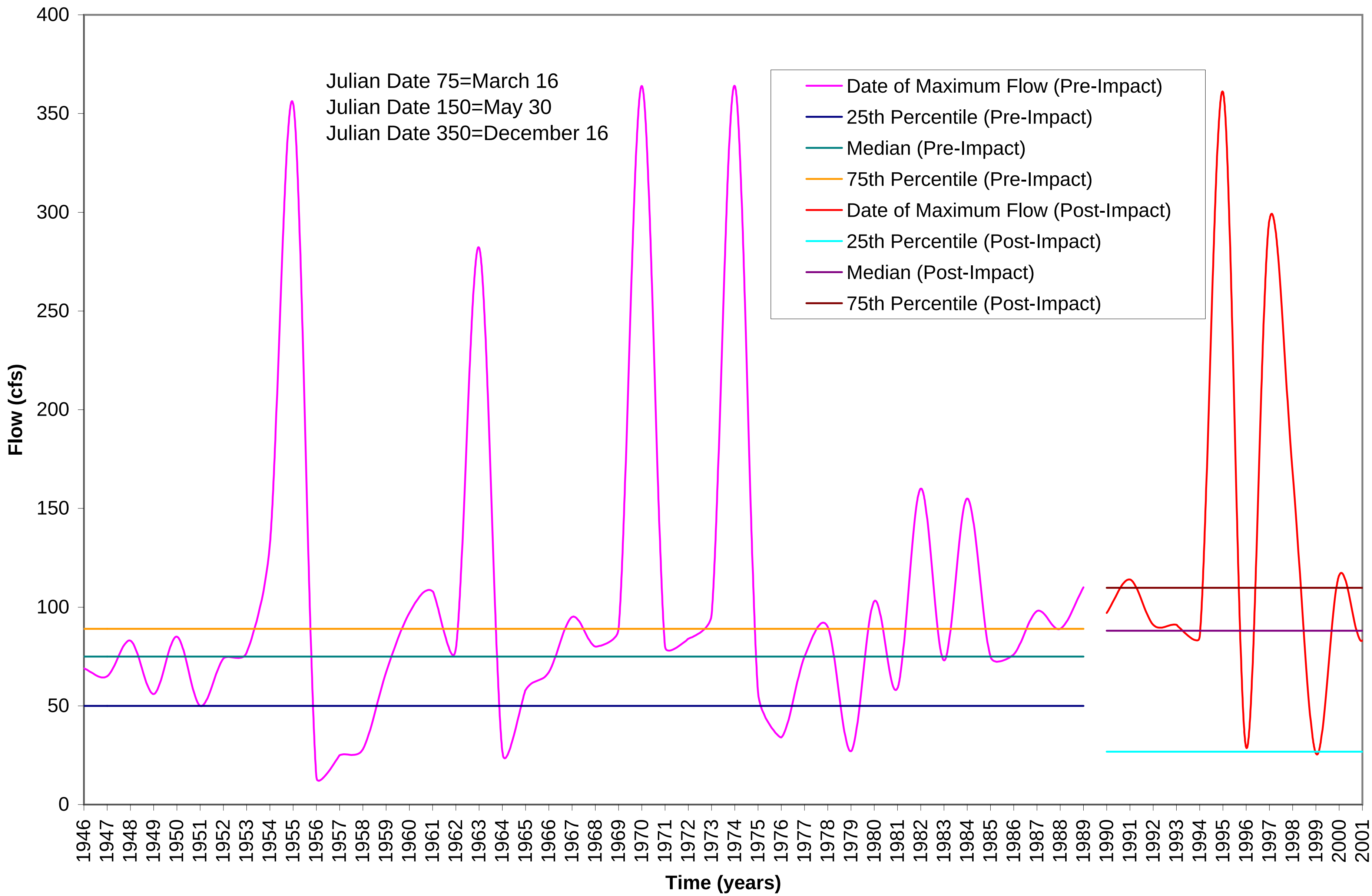


Figure B-25: Parker River USGS Gage at Byfield Julian Date of Annual 1-Day Minimum Flow (Pre and Post Impact Assessment)

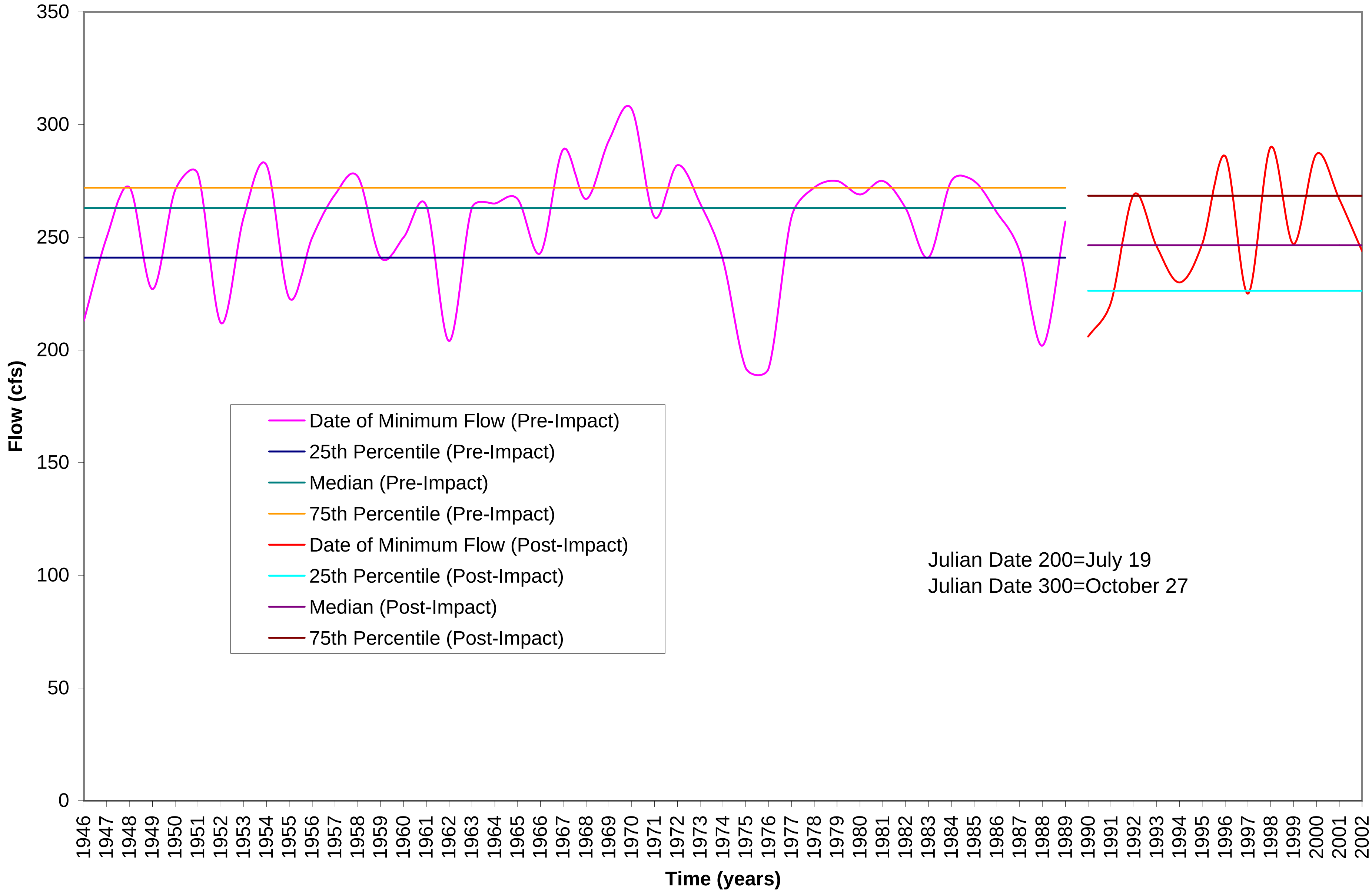


Figure B-26: Parker River USGS Gage at Byfield Number of Low Pulses (Pre and Post Impact Assessment)

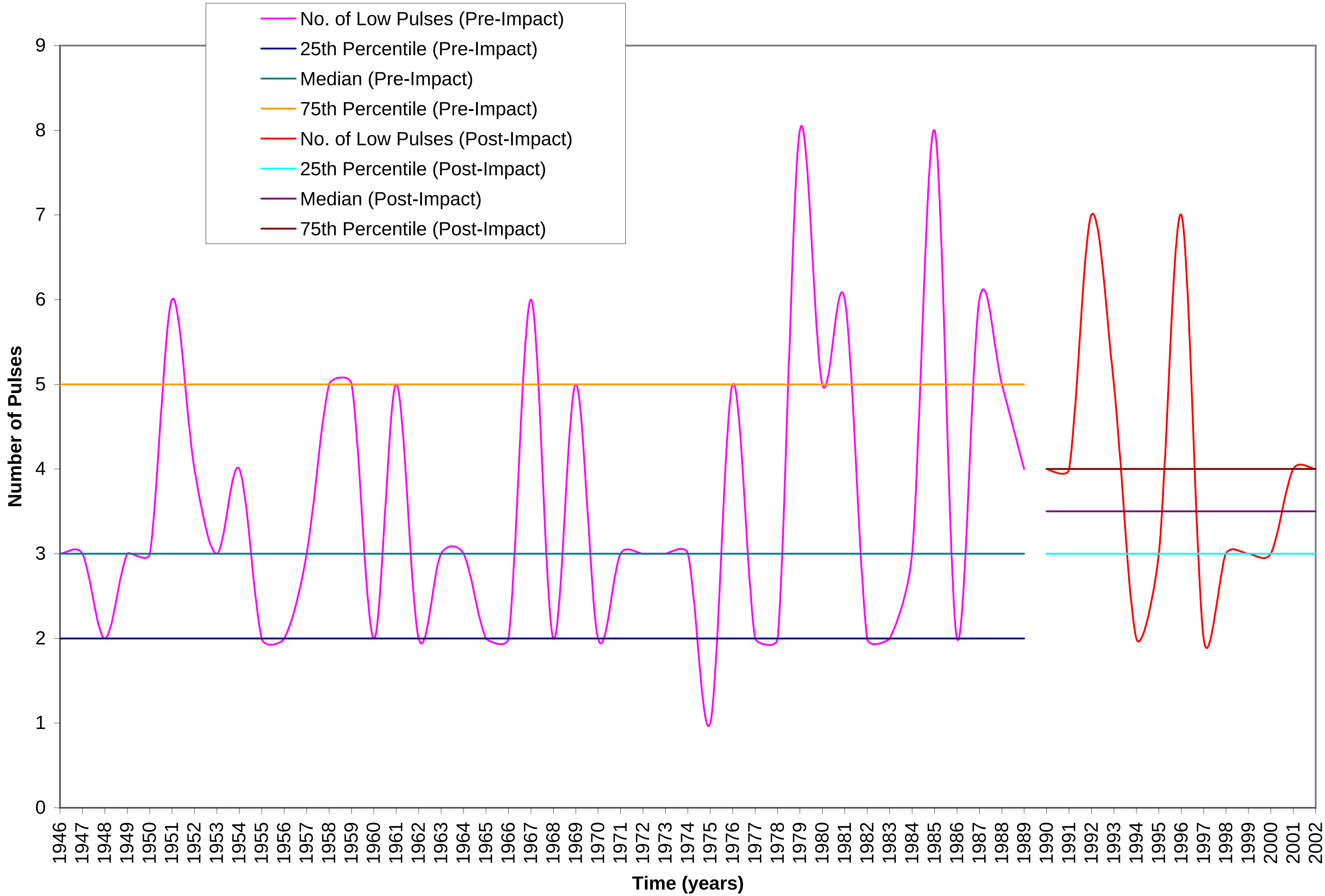


Figure B-27: Parker River USGS Gage at Byfield Number of High Pulses (Pre and Post Impact Assessment)

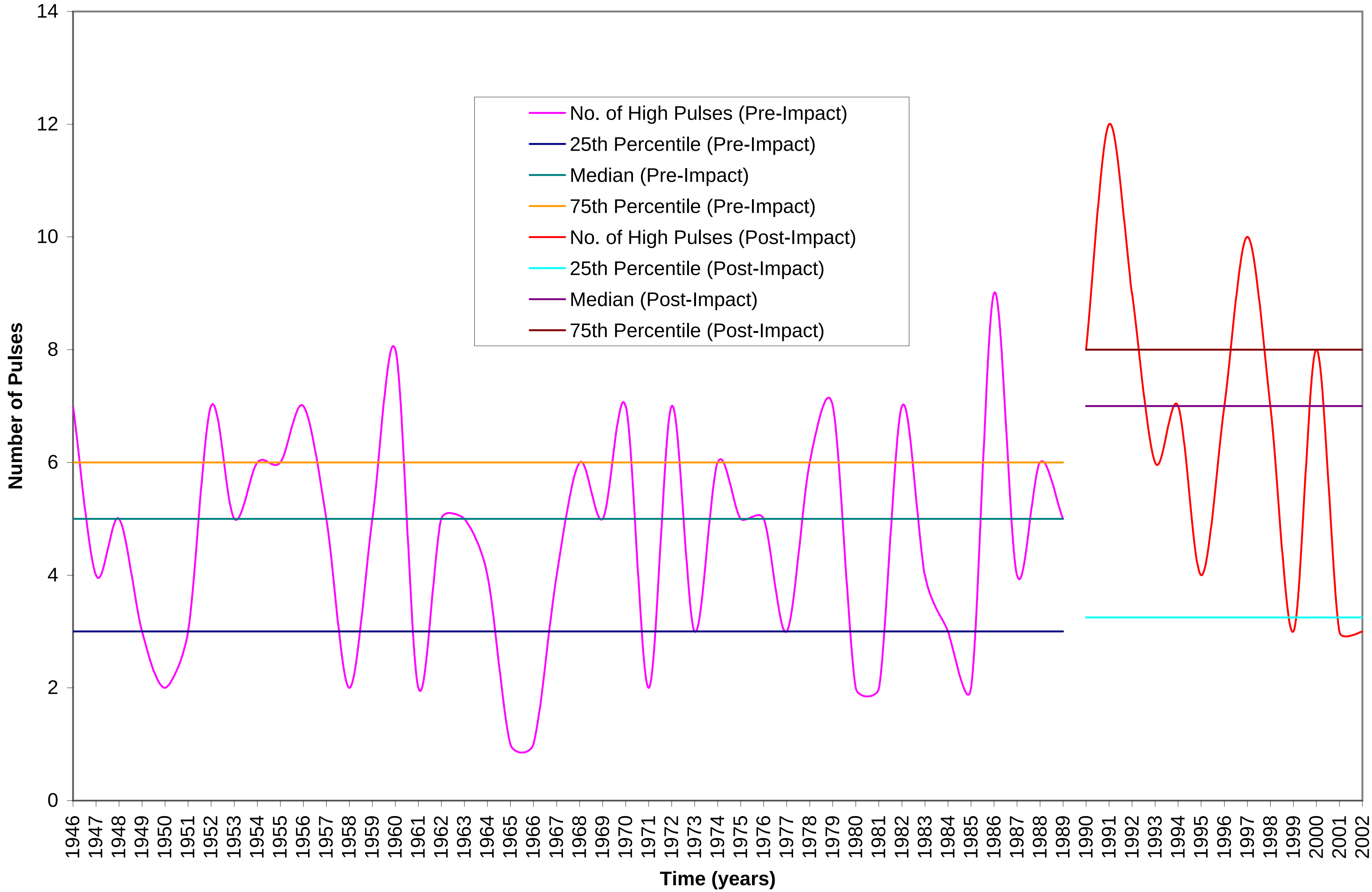


Figure B-28: Parker River USGS Gage at Byfield Low Pulse Duration (Pre and Post Impact Assessment)

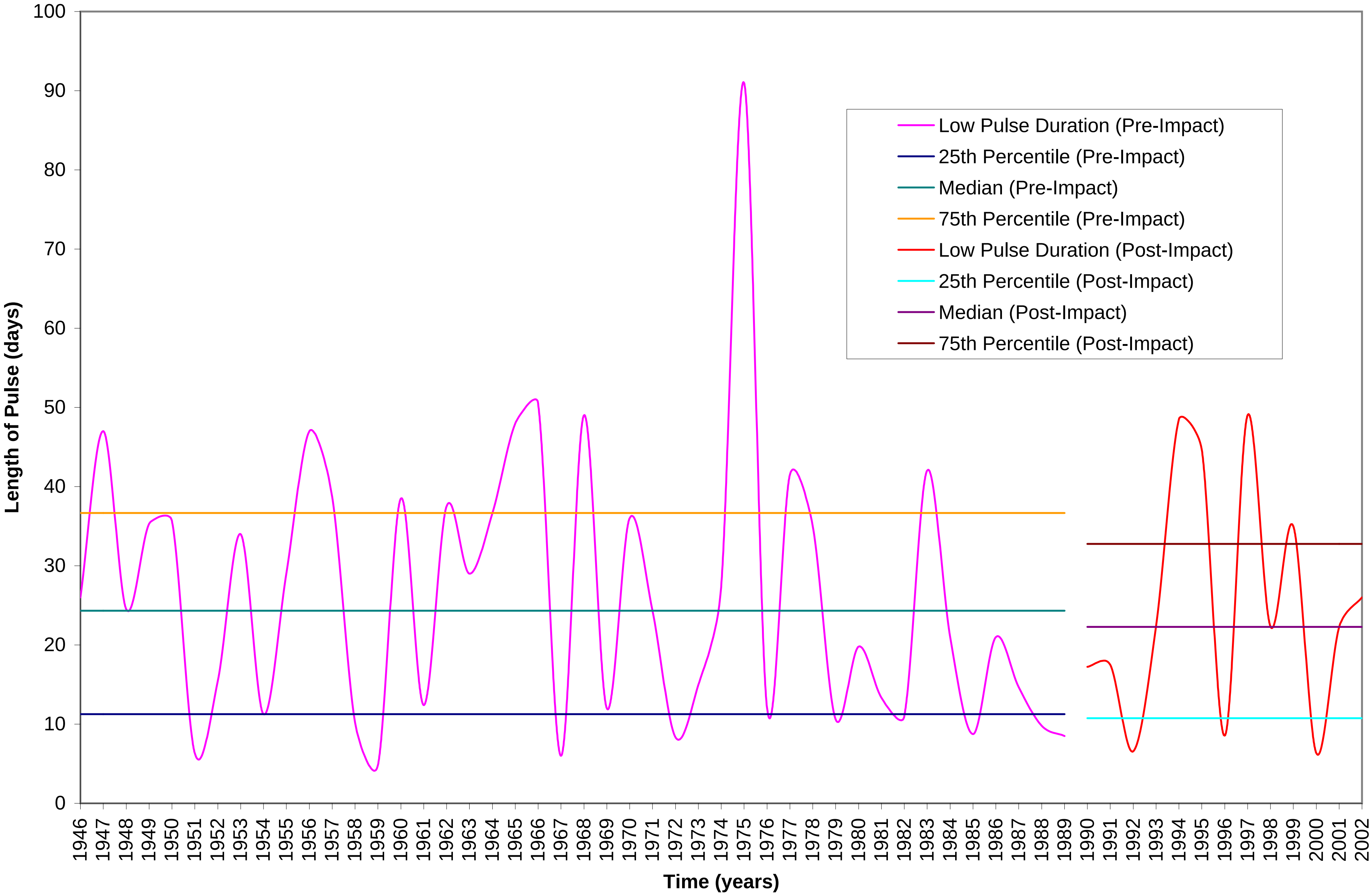


Figure B-29: Parker River USGS Gage at Byfield High Pulse Duration (Pre and Post Impact Assessment)

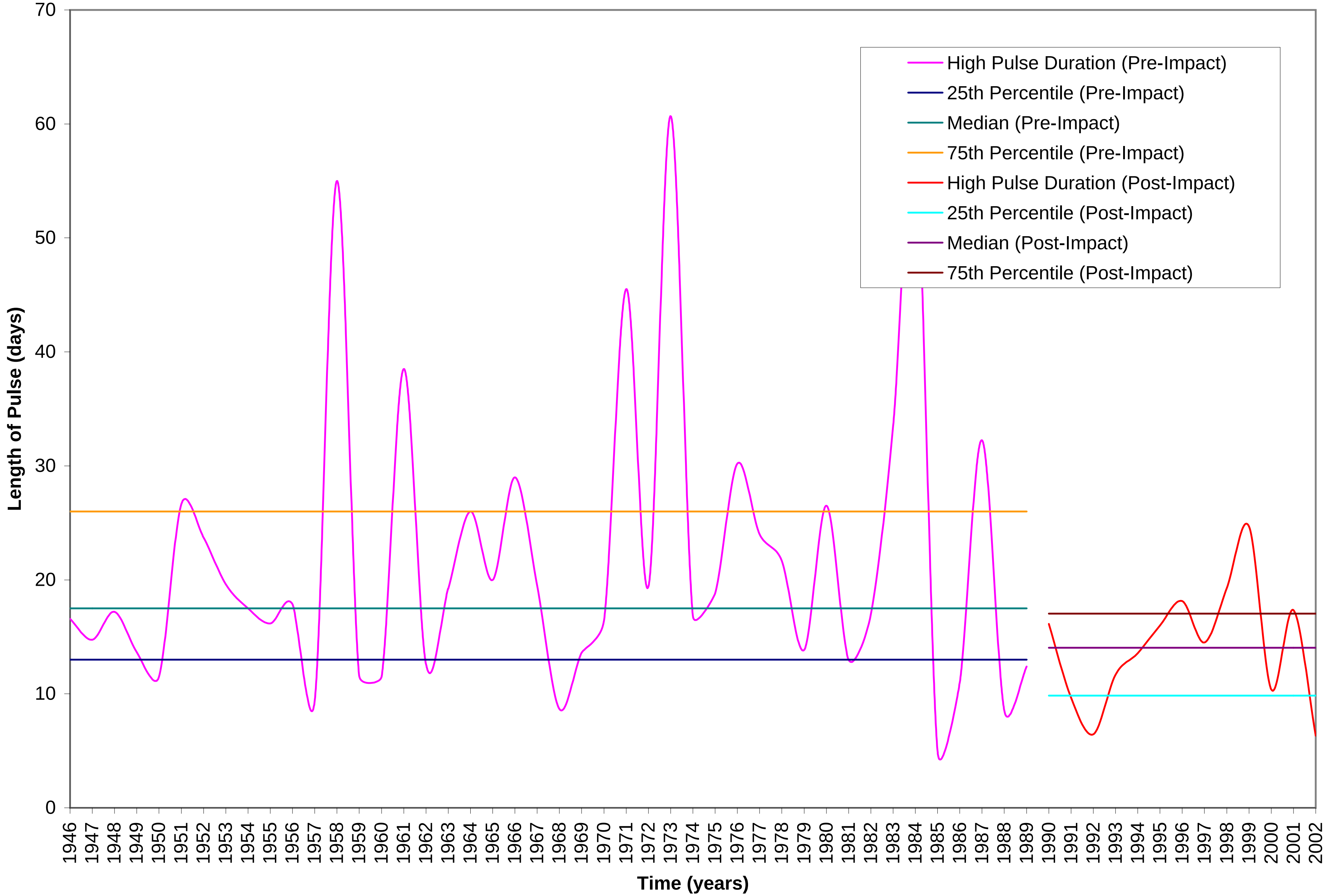


Figure B-30: Parker River USGS Gage at Byfield Rise Rate (Pre and Post Impact Assessment)

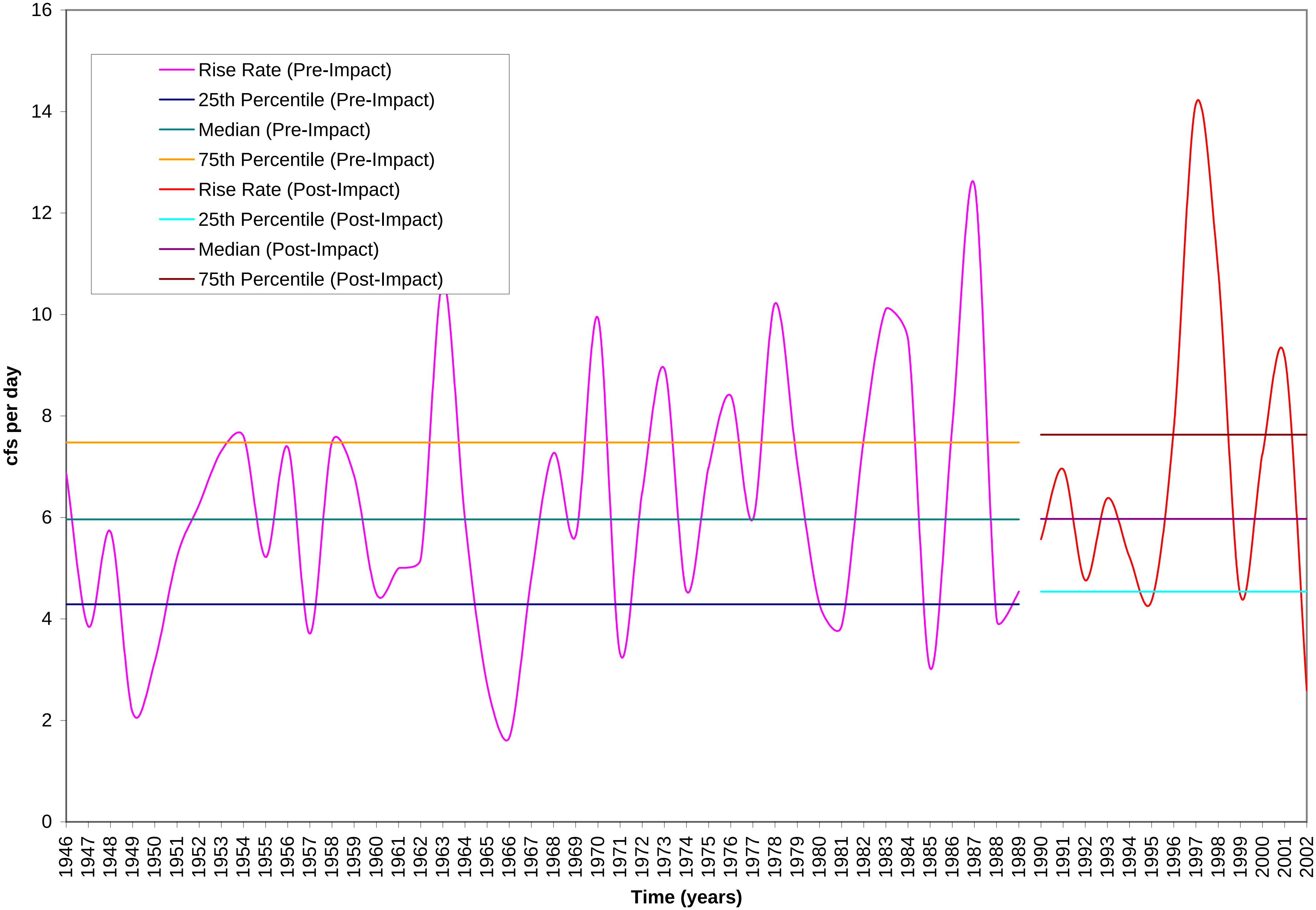


Figure B-31: Parker River USGS Gage at Byfield Fall Rate (Pre and Post Impact Assessment)

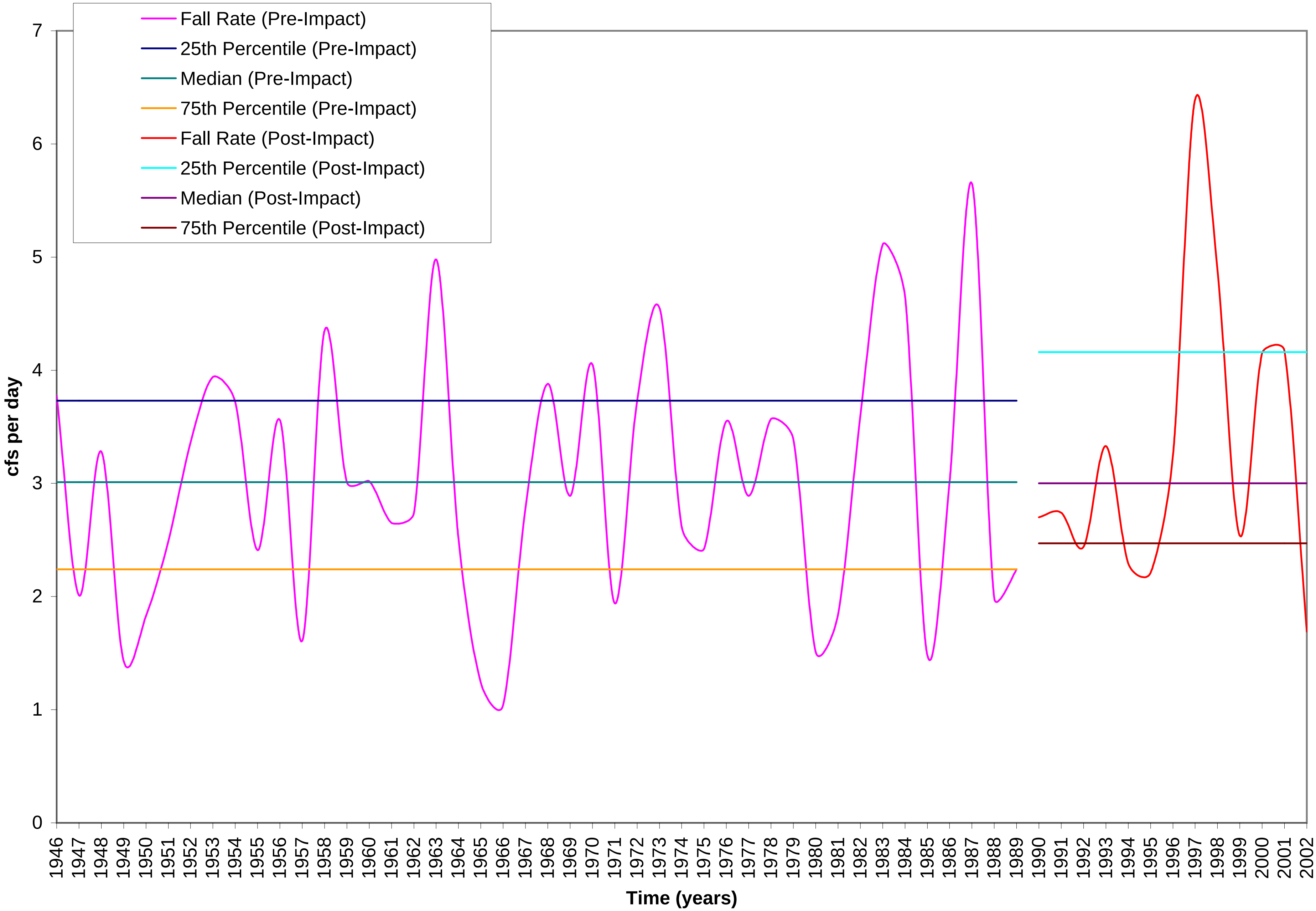


Figure B-32: Parker River USGS Gage at Byfield Number of Reversals (Pre and Post Impact Assessment)